THE UNIVERSITY OF TEXAS BULLETIN
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THE GEOLOGY OF HEMPHILL COUNTY, TEXAS

By

LYMAN C. REED AND OSCAR M. LONGNECKER, JR.

Bureau of Economic Geology
E. H. Sellards, Director

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of Democracy, and while guided and controlled by virtue, the noblest attribute of man. It is the only dictator that freemen acknowledge, and the only security which freemen desire.

Mirabeau B. Lamar

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FOREWORD

By Charles Laurence Baker

The accompanying geologic report of Hemphill County is the result of a detailed study of an area in the southern High Plains. Hemphill County happens to be the most strategic area for such a study because here the Canadian River emerges from its broad and deep valley, which cuts entirely across the great plateau or mesa of the High Plains. The area is also in the Anadarko basin, which is the leading structural feature of western Oklahoma and of the northeastern Texas Panhandle.

It was suspected before field work was started that fossil mammals would be found in the High Plains deposits in this county. The present writer accordingly instituted a search for them at the beginning and found them the first day in the field. This encouraged further attempts, the result of which was the discovery of one of the most prolific fossil fields of Lower Pliocene age yet discovered. This find renders it probable that the Canadian Valley across the High Plains will yield further important discoveries. These fossils are important not only to paleontology and zoology but also to the general and economic geology of the Southwest.

The Cenozoic deposits of the High Plains were laid down after the latest major uplift of the mountain ranges to the west. Of the formations deposited clearly after, and as a result of, the mountain-making movements, these deposits in Hemphill County and the Santa Fe formation in the upper Rio Grande Valley in New Mexico are the only ones which so far have yielded fossils from which the ages of the respective beds are determinable. Both, moreover, have fossils closely agreeing in age, hence they well establish the date of formation of the mountains. Those in Hemphill County also prove that the basaltic eruptions of eastern New Mexico began as early as Lower Pliocene.

It was fortunate indeed that the fossils found in Hemphill County and those collected at earlier dates from the eastern Llano Estacado farther south and the deposits containing them were studied by Dr. W. D. Matthew. He was able to show that the fossils from the Llano Estacado formerly referred to various stages of the Miocene are really Lower Pliocene. He and the present writer, from somewhat different points of view, became convinced that the bulk of the deposits are eolian in origin, in part worked over and redeposited by the wind from original stream-laid deposits formed in

the area itself, and in part transported by the wind from more distant sources farther west. The untimely death of Dr. Matthew, at the time when his great intellectual powers were at their zenith, is universally regretted by his colleagues both here and abroad. He was a leading authority on fossil mammals.

Up to the date of this publication the following papers on Lower Pliocene mammals from Hemphill County have been issued as parts of the publications of the Department of Geological Sciences of the University of California: Osteology and affinities of Borophagus by W. D. Matthew and R. A. Stirton, vol. 19, no. 7, pp. 171–216, 1930; Equidae from the Pliocene of Texas by W. D. Matthew and R. A. Stirton, vol. 19, no. 17, pp. 349–396, 1930; Critical observations on the phylogeny of the rhinoceroses by W. D. Matthew, vol. 20, no. 1, pp. 1–9, 1931; Machaerodus catocopis Cope from the Pliocene of Texas by Wm. Henry Burt, vol. 20, no. 7, pp. 261–292, 1931; A review of the rhinoceroses with a description of Aphelops material from the Pliocene of Texas by W. D. Matthew, vol. 20, no. 12, pp. 411–480, 1932; and A new genus of Artiodactyla from the Clarendon Lower Pliocene of Texas by R. A. Stirton, vol. 21, no. 6, pp. 147–168, 1932.

The results of plane table mapping in Hemphill County indicate that the various layers of the Lower Pliocene sediments were originally laid down in beds of nearly uniform thickness over a hill-and-valley topography in much the same manner as the loess of the upper Mississippi basin. This affords a new criterion which is apparently first-rate evidence of eolian origin. It is one which can be profitably used in other areas of non-marine sediments.

The Cenozoic section of Hemphill County is the thickest yet known on the High Plains. Because this area lies in the Anadarko synclinal basin and because the Cenozoic is exceptionally thin over the Amarillo uplift, where the Canadian River is now superposed over the older strata, it is reasonable to infer from effect to cause, that the Amarillo uplift was upfolded and the Anadarko Basin downfolded contemporaneously with the last Cordilleran orogeny, which was just previous to, or in part contemporaneous with, the Lower Pliocene sedimentation. This inference is of great importance in its bearings on prospects for oil, gas and potash in the west Texas and eastern New Mexican region of eastern flank folds of the Cordillera.

THE GEOLOGY OF HEMPHILL COUNTY, TEXAS

BY

LYMAN C. REED AND OSCAR M. LONGNECKER, JR.

INTRODUCTION

Hemphill County is the second county south of the northeast corner of the Panhandle of Texas. It is bounded on the east by the 100th Meridian, and the 30th Parallel of Latitude passes through its northern part. To the north is Lipscomb County, to the west Roberts County, and to the south Wheeler County. East of Hemphill County are Roger Mills and Ellis counties in Oklahoma.

The main line of the Santa Fe Railroad (P. & S. F. R.R.) passes across the northwest portion of the county through Mendota, Canadian, and Glazier. A recently completed branch of the Santa Fe from Cheyenne, Oklahoma, to Pampa, Texas, crosses the southeast corner of the county within a mile of Zybach. The county is very well served by highways and roads, all of which are graded dirt roads. State Highways No. 4 and 33 pass through it from north to south, and two east-west highways connect with the Oklahoma state highway system.

NATURE AND IMPORTANCE OF THE WORK

The data available for this report are the result of a geologic investigation carried on by the writers in Hemphill County during the summer and winter of 1928 and the early part of 1929 for the Rio Bravo Oil Company, to determine whether or not geologic structure has been reflected in the beds which make up the plains of the Panhandle, to determine the age of those beds, and to make a detailed geologic map of the county.

The vertebrate fossils found in connection with this work were referred to the late Dr. W. D. Matthew of the University of California Paleontological Museum for identification. These fossils have been useful in making a correlation of the strata within the area, and of this area with other areas in the region. As the material available seemed to be abundant, further work was undertaken by the University of California Museum, and extensive quarrying was carried on.

Issued January, 1933.

The present report includes the first detailed map of Hemphill County. The accuracy of mapping in the county was furthered by bench marks left by the United States Coast and Geodetic Survey in its survey of the 100th Meridian to establish the Texas-Oklahoma state boundary. The drainage is completely mapped. In addition to the areal map there are cross sections of parts of the area.

AVAILABLE PUBLICATIONS

The writers found little in the available literature to help them in their detailed investigation in Hemphill County because all earlier work either had been largely of a reconnaissance nature or did not deal with the immediate area. For reference, however, a partial list of the literature dealing with the geology of the Llano Estacado and the High Plains of the Texas Panhandle is given.

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ACKNOWLEDGMENTS

The authors wish to express their appreciation to the Rio Bravo Oil Company for the opportunity of making this study and for permission to publish the results. The assistance rendered by Mr. Charles Laurence Baker through suggestions and criticism and in directing the work has been invaluable. We are fortunate to have had the benefit of his experience and are grateful to him for having read and criticized the paper in its finished form. The value of the paper has been much enhanced by the coöperation of the late Dr. W. D. Matthew, who, with other members of the paleontological department at the University of California, examined and determined the fossil specimens which the authors discovered and collected, and who, through untiring correspondence and an unpublished manuscript, gave the benefit of his experience in the plains geology and paleontology. The collections of Mr. R. A. Stirton, Dr. Charles L. Camp, and Mr. V. L. Vanderhoof, who were in charge of the several field parties which collected material from the various localities for the University of California, have been of the greatest assistance. Dr. Junius Henderson very kindly determined the gastropod material which was collected from the Canadian River terraces.

The authors wish to thank Judge H. E. Hoover of Canadian for furnishing them with the log and samples of his Hoover No. 1 well. The other well logs were furnished by Mr. C. Max Bauer of the Midwest Oil Company at Amarillo. We are indebted to Mr. Rudolph Goettsche of Higgins, Texas, for directing us to Localities 26A and 26B in Lipscomb County, and to Mr. C. Coffee of Miami, Roberts County, and to Mr. Sibet of Lipscomb County, for permission to remove fossils from localities on their land. We are grateful to Mr. H. E. Hoover, Jr., for a number of the details included in this report and for his assistance in many ways.

The Santa Fe Railroad graciously gave their permission to publish their logs and cross section of the soundings for the railroad bridge across the Canadian River at Canadian and their information regarding a water well drilled at Canadian. The Southern Pacific Railroad (E. P. & S. W. Branch)

and the Rock Island Railroad furnished profiles of their lines in New Mexico, from which elevation data have been taken to give information on the gradient of the Canadian River from New Mexico into Texas and on the relation of Hemphill County to the Cretaceous formations on those lines.

It is impossible to list all of the friends to whom we are indebted for assistance and who made our stay of eight months in Canadian so pleasant, but we are deeply appreciative of the private and official courtesies shown us.

PHYSIOGRAPHY

Location and General Statements.—Hemphill County is situated on the border between the High Plains and the Central Lowland provinces. The former or western province north of the Canadian River is called the Panhandle High Plains, and south of the river, the Llano Estacado or Staked Plains. The eastern part of the county has been called the Eroded Plains, while the northeast corner may be classed as a remnant of the Panhandle High Plains. The western part of Hemphill County is occupied by high land and the eastern part by low land. The Canadian River which flows from west to east through the north central part of the county; Red Deer Creek, a tributary of the Canadian, which flows through the southwest quarter of the county; and the Washita River, which parallels the Canadian some 6 or 8 miles south and heads within the boundaries of the county, are the major drainage channels.

The present topography of Hemphill County is the result of the upbuilding of the High Plains, which in that county culminated and ended at the end of the Lower Pliocene, modified by the subsequent work of the Canadian River and its tributaries and the work of the wind, weathering, and the agencies of man during Pleistocene and recent epochs. In the western part of the county both north and south of the Canadian River valley where the elevation is highest, one observes the level uniform aspect of the tops of the escarpments and mesas which represent the approximate surface of the High Plains at the end of the Lower Pliocene time. This breaks off abruptly into the valley of the Canadian in an abrupt scarp which follows an extremely ragged line. The work of the Canadian River and its tributaries at various periods through the Pleistocene to the present day is expressed in the multitude of tributary streams, arroyos, and minor drainages, and in the enormous amount of material which has been removed and carried out through the Canadian channel to bring the surface of the valley from the level

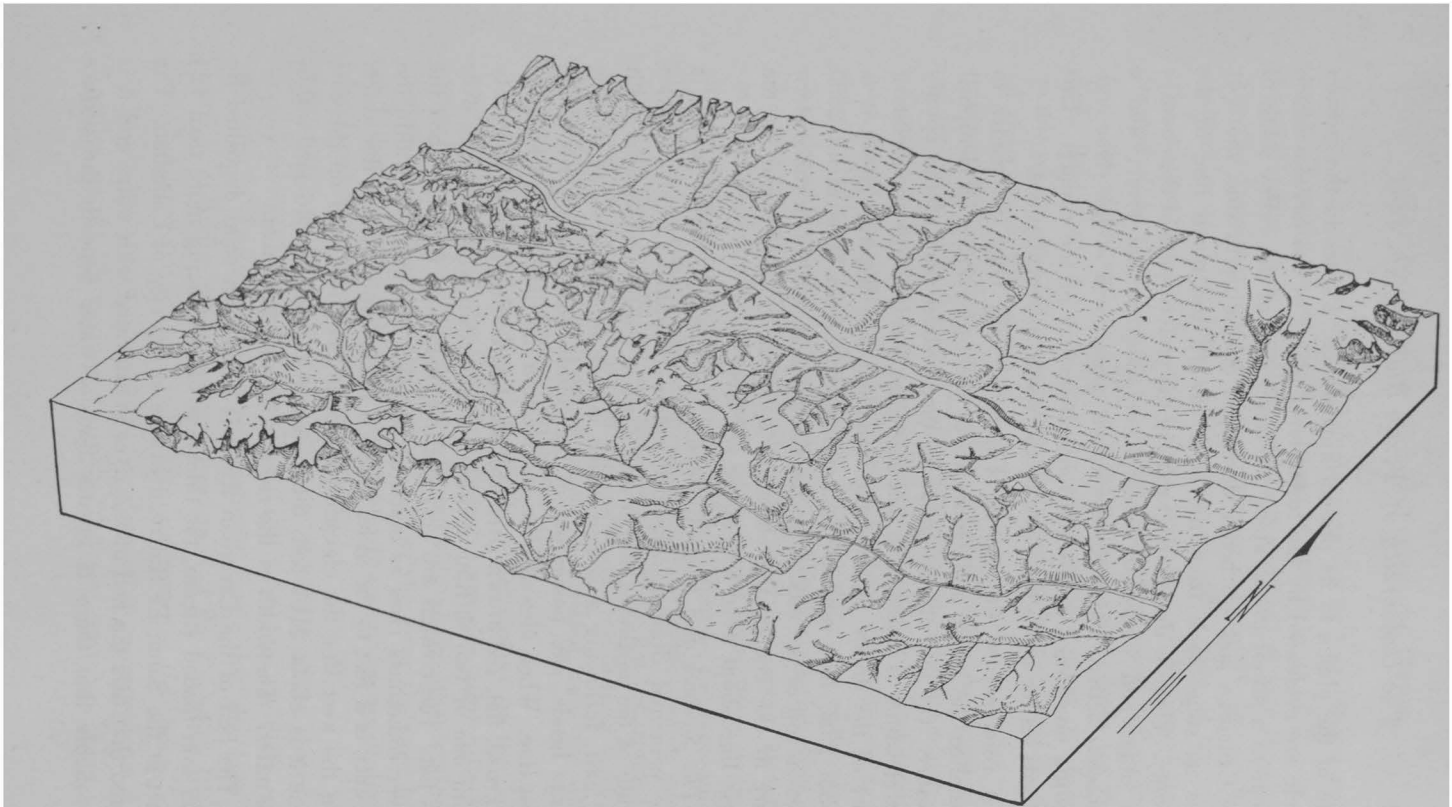

Fig. 1. Sketch showing topographic relief in Hemphill County, Texas.

line of the plains to its present appearance. Pauses in the erosion cycle are evidenced by the lower level plains of the terraces which occur to a minor extent along the lower part of the valley south of the Canadian and are better developed on the north side, more or less as steps back from the river toward the north line of the county. There is dune topography in the eastern part of the county; an older and dissected development south of the river; and a younger, active, and fully developed stage north of the river continuing northward across the north boundary of the county. This affords testimony to the work of the winds in recent times.

A reference to the sketch (Figure 1) will help the reader to visualize the relief and character of the topography in Hemphill County. On top of the plains in the western part of the county the elevation is about 2875 feet above sea level, on the southwestern part of the divide between the Canadian and Washita rivers it is about 2550 feet, and in the northeastern corner it is about 2550 feet on top of the mesas. In the Canadian River bed in the eastern part of the county the elevation is about 2170 feet and on the west line about 2410 feet above sea level.

The Streams and Their Valleys.—The Canadian River, which is the principal drainage channel, enters Hemphill County 5 miles south of the northwest corner and flows in a direction slightly south of east, following a course which is free of meanders as well as large bends, and passes out of the county near the middle of the east line. When viewed from an elevation the river bed is seen to be a broad, flat, red-brown stretch of sand extending across the county with one or two shifting rivulets of red-brown water winding over its flat. The rivulets are very shallow, though at times of flood the river sometimes rises as much as 20 feet. The gradient within the county is 8 feet to the mile, giving a fairly rapid flow to the water. On the west line the elevation is about 2413 feet, and on the east line it is about 2167 feet, thus making a grade of 246 feet within 30 miles. The width of the river is ¾ mile in places.

The bed of the Canadian River is filled with sand deposited by the over-loaded stream, the thickness of sand being more than 123 feet at the Santa Fe Railroad bridge at the city of Canadian. The sand that fills the bed of the river is saturated with water and it is probable that there is greater flow of water beneath the surface

than on top. The river bed is notorious for its treacherous quicksands. The top of the flood plain is bordered by a bluff 5 to 10 feet in height, and the alluvium has a width of a mile in places. The flood plain is made up of swampy or marshy or dry or dune-spotted areas. The characteristic form on either side of the river, and accentuated on the north side, is a row of low sand dunes formed along the banks by the high winds which blow prevailingly from the south and remove large quantities of sand from the river bed. Behind these dunes there are often marshy areas or shallow ponds which are fed by seepages. Tall grass with occasional clusters of trees covers this area.

River terraces occur from 50 to 100 feet above the flood plain of the river. On the south side there are two terraces which are dissected and isolated by the tributary drainage of the Canadian, and there is a gradual rise of the land from the terraces to the base of the mesas and escarpments. In the eastern part of the county this rise is gentle to the top of the divide between the Canadian and Washita rivers. On the north side of the river the general elevation of the top of the terrace extends back several miles from the river in the western part of the county before rising to the escarpment, though in the central part it extends back 6 or 7 miles before gently rising to the north line of the county where the escarpment is reached. In the eastern part of the county this uniformity in elevation at the top of the terraces extends northward until the older outcrops are reached in the northeast corner.

There is marked contrast between the physiography on the north and south sides of the Canadian River. Extensive sand hills and dunes are found on the north side and this sandy area is almost devoid of surface drainage, while south of the river the sand hills and dunes are absent, and the minor drainage is much better developed and improves to the eastward.

Red Deer Creek, which is a tributary of the Canadian, enters the county north of the southwest corner and flows into the river near the city of Canadian. In every respect, except for the lack of terraces, it might be classed as a miniature of the Canadian River. It is bordered on either side by high escarpments and mesas, and its valley from rim to rim might be estimated to measure from 2 to 5 miles across, depending upon the distance upstream from the

Canadian River. Its tributary drainage is of the same nature as that on the south side of the Canadian. On the west line of the county the difference in elevation between the creek bed and the top of the plains is about 200 feet, while at the mouth it is about 400 feet.

The Washita River, whose valley lies in the southern part of the county, is in no respect similar to either the Canadian River or Red Deer Creek. On the west line of the county the headwaters of the Washita finger out into a series of tributaries and are enclosed within a U-shaped basin. This basin, bounded by an escarpment of plains, is open to the east and extends in that direction for about 15 miles on either side of the river. The Washita contains clear running water, supplied from seepages and springs along its course. The course of the river is winding but not meandering. Bordering it is alluvium, dotted with sand dunes and containing marshes and sloughs from former creek channels. Although the mouths of the two rivers are many miles apart, in the eastern part of Hemphill County the Washita and Canadian rivers are but 8 miles distant from each other.

The valley of the Washita River is relatively shallow, with gentle sloping sides which descend from the escarpment at the divides. At the east line of the county the steep gradient has brought the channel of the Washita down to nearly the level of the Canadian. North of the river there is a belt of sand dunes, part of the material of which was blown from the bed of the river.

There are relatively few creeks within the county which have running water in their channels. Often one part of the stream carries water while another part is dry. North of the Canadian River one creek, Horse Creek, is running in both its main branches where they cross the north line of the county, but from about 2 miles south of the line to the Canadian River it is dry with the exception of a few isolated water holes. In the creeks farther east the opposite is true; they are dry in their upper parts and obtain their water from springs at the base of the terrace. About 4 miles east of the city of Canadian, on the south side of the Canadian River, Elk Creek is flowing about the lower 3 miles of its course and there is also a local stream of water in its upper reaches. This and Gageby Creek, a permanently flowing creek in the southern part of the

county, are the only creeks on the south side of the Canadian River which carry permanent water.

In the eastern part of the county, north of the Canadian River, Clear, Persimmon, Boggy, and Oasis creeks probably flowed from seepages near their mouths for quite a period before cutting back as far as their present headwaters, and above the point of the springs their valleys are relatively insignificant. It would seem in addition, as in the case of Washburn Arroyo which is situated northwest of Red Deer Creek and which may at one time have flowed before it choked itself with sand, that the gradation between flowing and dry streams in Hemphill County is merely a matter of the amount of sand in the creek bed.

However, the dry channels and washes form a topographic division which embraces a gradation of drainage channels from the small gully up to the large dry wash, but the most typical are the dry washes which descend from the escarpments or high lands into the major streams. These vary in length from 1 to 8 miles. Many of the gullies are the result of overstocking the ranges. Once the crust of matted grass, hardpan, or indurated rock ledge is broken through, the down-cutting is rapid. As only soft materials lie underneath, sapping and undermining aid in enlarging the cut, and the vertical bluffs on either side are held up by the resistant cap. These dry creeks carry a great deal of debris from the high land in times of rainfall. Their upper courses are usually clear, but their lower parts are heavily choked with sand.

Within the sand hill areas the drainage channels are relatively simple, for the courses are long with gentle bends and no meanders. In places the valleys of these streams are 2 miles wide and very shallow, and chains of lakes or depressions within them are characteristic. Most of the drainage is subterranean and only in times of very heavy rain do the channels carry water.

Sand Hills and Dunes.—The greatest development of blown sand in the county is north of the Canadian River and occupies the greater part of that area. In the southern portion of the area north of the river, the dunes are more pronounced than in the northern part. From the town of Glazier north and east there are relatively few dunes, and this area contains broad sandy flats with an occasional low sand ridge. The southern part of the area is crowded

with sand dunes, most of them semi-active, with some active ones just north of the river and east of the Conatser Ranch and Locality 25 in the eastern part of the county. The dunes vary in height from 10 to 50 feet and average about 30 feet. They are covered by a growth of grass, sage and a few wild plum thickets, all of which tend to make them stationary. At a number of places there are "blow-outs" which spread over several acres. The sand composing the dunes is fine-grained and of buff color.

The area in the southeastern corner of the county is covered by both active and semi-active dunes and sand ridges. A thick mantle of scrub oak and the tributaries of Hackberry Creek have altered the typical dune topography to that of sand hills occupying the tops of the local divides. North of the Washita River there is a narrow strip of semi-active dunes which have been formed chiefly by sand blown from the bed of the river.

Cap Rock and Plains.—In the western part of the county there are remnants of the plains which once extended eastward over the entire county but which have subsequently been eroded to their present form. It is only in the southwest corner of the county and in a small area north of Red Deer Creek in Roberts County that the tops of the plains are not eroded. From the western part of the county eastward the plains have been eroded to the successive levels of lower resistant beds which form a series of benches.

The composition of the top of the plains varies from a black clay to a brown sandy soil which supports a good mantle of grass. The surface of the plains is flat, but near the edge the top is a series of low rolling hills. Above the uppermost cap there are 75 feet of beds which are easily eroded into hills down to the cap rock. The same is true of the lower caps, for each has an overburden. When all of the overburden is removed the cap forms a flat plain. This is true on many of the escarpments and mesas east of the highest plains in the county.

STRATIGRAPHY

PERMIAN (?) RED BEDS

These beds are indicated on the areal map as small, isolated exposures, the most extensive of which are along the Canadian River in the eastern part of the county. In the Washita River valley the

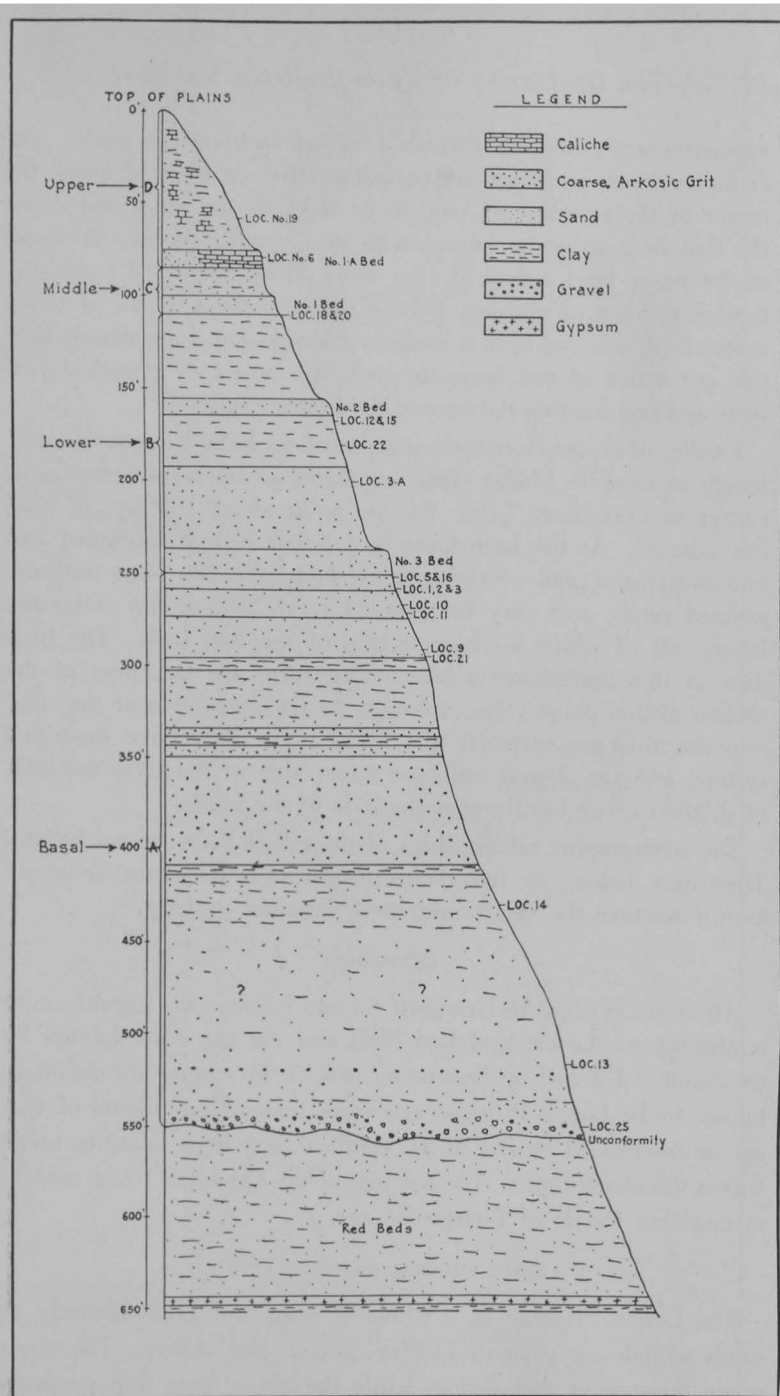

Fig. 2. Composite section of Lower Pliocene and Permian (?) Red Beds showing stratigraphic levels of fossil localities in Hemphill County, Texas.

exposures are poor and furnish no good sections for study. The farthermost exposure up the Canadian River is situated about the center of the east line of Coördinate K-11 on the map, and shows the Red Beds to be in contact with the Lower Pliocene. It shows at the water level a bed of very fine-grained indurated sand containing veinlets of gypsum. Above this are about 2 feet of loose, unstratified, soft, red-brown, medium-grained sand. Immediately over this are 2 feet of conglomerate made up mostly of reworked Red Beds and representing the base of the Lower Pliocene.

Farther down the river there is an excellent section of considerable length exposed in bluffs. This is situated in the northwesternmost corner of Coördinate L-14. At this point about 100 feet of beds are exposed. At the base there is a 3-foot bed of crumpled and broken gypsum, and overlying it are beds of sandy clay, medium-grained sands, and very fine-grained sands with a few indurated layers, all of which is characteristic of the Red Beds. The high dips in this immediate vicinity account for the thickness of the section at this point. The exposures on the north side of the river opposite this are virtually the same as in the above described section, and for several miles on either side of the river the beds of gypsum occur locally near the base of the bluffs.

The stratigraphic relationships of these Red Beds are not known. They may belong to the Quartermaster, but it is not definitely known whether the Quartermaster is Permian or later.

CENOZOIC

All strata exposed in Hemphill County between the unconformity at the top of the exposed Red Beds and the cap rock formed by the Number 1-A bed in the western part of the county are definitely known to be Lower Pliocene age since mammalian fossils of that age as determined by Dr. W. D. Matthew have been found to range within the above limits. The terraces of the Canadian River contain mammalian fossils of Pleistocene age.

LOWER PLIOCENE (HEMPHILL BEDS)

The Lower Pliocene as a whole is composed predominantly of sands with lesser amounts of clay, gravel, and caliche. The sands occur throughout the section, while the clays form thin partings.

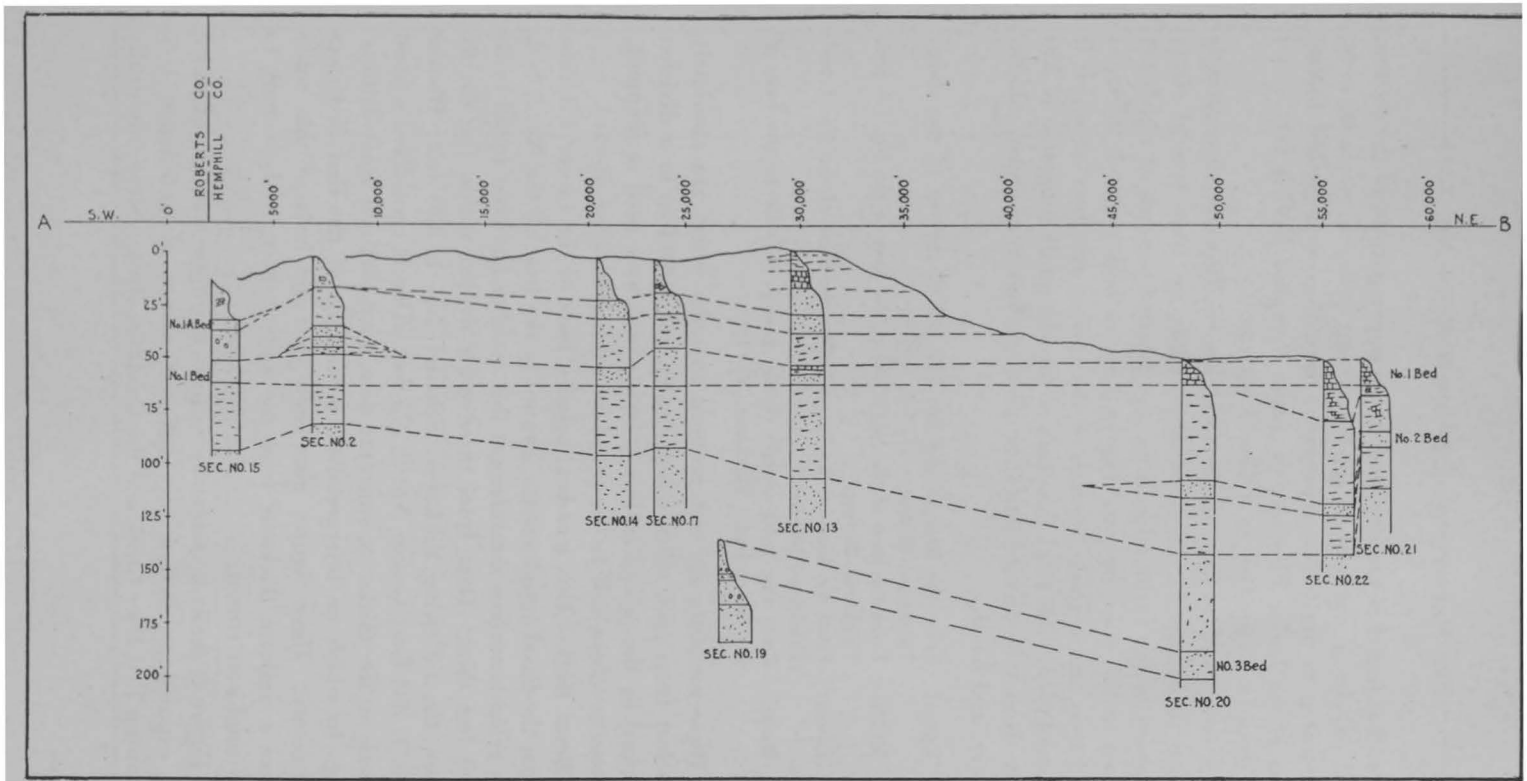

Fig. 3. Sections of lower Pliocene along line A-B, Hemphill County, Texas.

Gravel is found at the base and in the upper portion of the section, and caliche is confined to the uppermost beds. Since these beds, according to the fauna, represent a heretofore undescribed formation of the Lower Pliocene, the name *Hemphill beds* is here given to them to be applied as a faunal horizon.

A composite section of the total Lower Pliocene succession is given in Figure 2. This section is made up from typical strata exposed in the various localities, the detailed sections of which are given in the other figures. Figure 2 shows both the true thickness and true stratigraphic position of the various members of which it is composed. The total thickness of the Hemphill formation is 550 feet. It may be divided into four members, known as upper, middle, lower, and basal.

Upper: From the base of the No. 1-A bed to the top of the plains. Thickness, 85 feet.

Middle: From the base of the No. 1 bed to the base of the No. 1-A bed. Thickness, 25 feet.

Lower: From the base of the No. 3 bed to the base of the No. 1 bed. Thickness, 140 feet.

Basal: From the basal contact of the Lower Pliocene to the base of the No. 3 bed. Thickness, 300 feet.

These members are not grouped in units which are absolutely distinct from each other lithologically but according to a division formed by the recognizable key beds which were used in mapping. These members will be described in order from base upward.

Basal Beds.—This member includes beds of the Lower Pliocene from the basal conglomerate upward to the base of the No. 3 bed. By reliable surface measurement this member has been found to be 300 feet thick. Data from three wells drilled within the county show the following thickness: Schaller No. 1, 320 feet; Hoover No. 1, 303 feet; George No. 1, 275 feet. This is considered a good check on the thickness, since the data were obtained from drillers' logs in which an interpretation of the top of the Red Beds was necessary. These figures also show that the beds of this series have a uniform thickness from the eastern part of the county to its southwest corner.

Figure 2 shows a composite section, the upper portion of which is exposed at Section 11, southwest corner of Coördinate H-5, between Red Deer Creek and the Canadian River. Stratigraphically

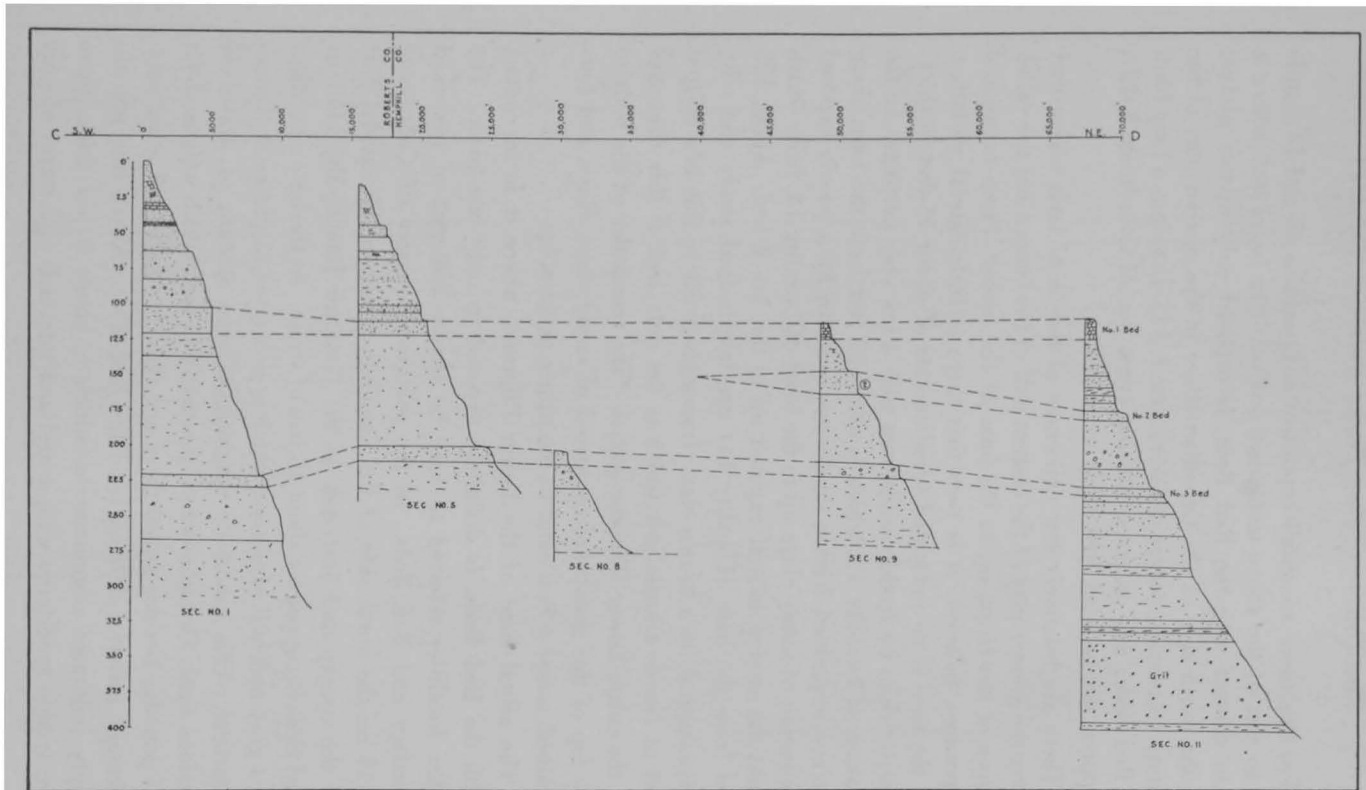

Fig. 4. Sections of Lower Pliocene along line C-D, Roberts and Hemphill counties, Texas.

below this there are small exposures at Localities 13 and 14 a mile or so east of the above mentioned section. The basal bed, where it is in contact with the Red Beds, is exposed only in two places: on the north side of the Canadian River in the eastern part of the county (southwest corner of Coördinate K-14), capping a long bluff of Red Beds; and on the south side (west line of Coördinate K-12), capping the isolated Red Beds exposure.

There are relatively few exposures of the basal beds where they cover the greater part of the eastern half of the county and the valley slopes of the rivers up to the base of the mesas. From occasional exposures, however, it is seen that there is little lateral variation. At the base is an indurated conglomerate of about 15 feet in thickness overlain by friable sandstones with a few clay partings. In the horizon of Locality 13, which is about 35 feet from the base, there are coarse-grained friable sandstones overlain by a poorly exposed succession of sandy clays up to the level of Locality 14, from which point the section is well exposed up to the No. 3 bed. About 125 feet from the base (Locality 14) are interbedded sandy and silty clays capped by a brown clay. Immediately above this is a 60-foot bed of coarse arkosic grit which is the only bed of this character in the entire Lower Pliocene section. The remainder of the beds to the top of this group are composed of sandy clays, clays, and fine-grained, massive buff sand in the upper portion.

The actual base of the Lower Pliocene, where it is in contact with the Red Beds, is definitely exposed in only one place. The other localities referred to may be terrace material of reworked Tertiary and Red Beds. In the southwest quarter of Coördinate K-14 on the north side of the Canadian River in the eastern part of the county and just east of the Conatser Ranch, the bluff of Red Beds is capped by about 15 feet of strata. At the base or contact is a gray and buff sandstone which is indurated in places to a semi-quartzite. This sandstone contains a large amount of gravel of various sizes. One boulder of quartzite was seen which weighs about 10 pounds. Besides gravel there are also clay balls and other fragmentary material derived from the Red Beds. Above this prevailingly indurated conglomerate, which is about 5 feet thick, there are friable sandstones with gravel and interbeds and lenses of gray

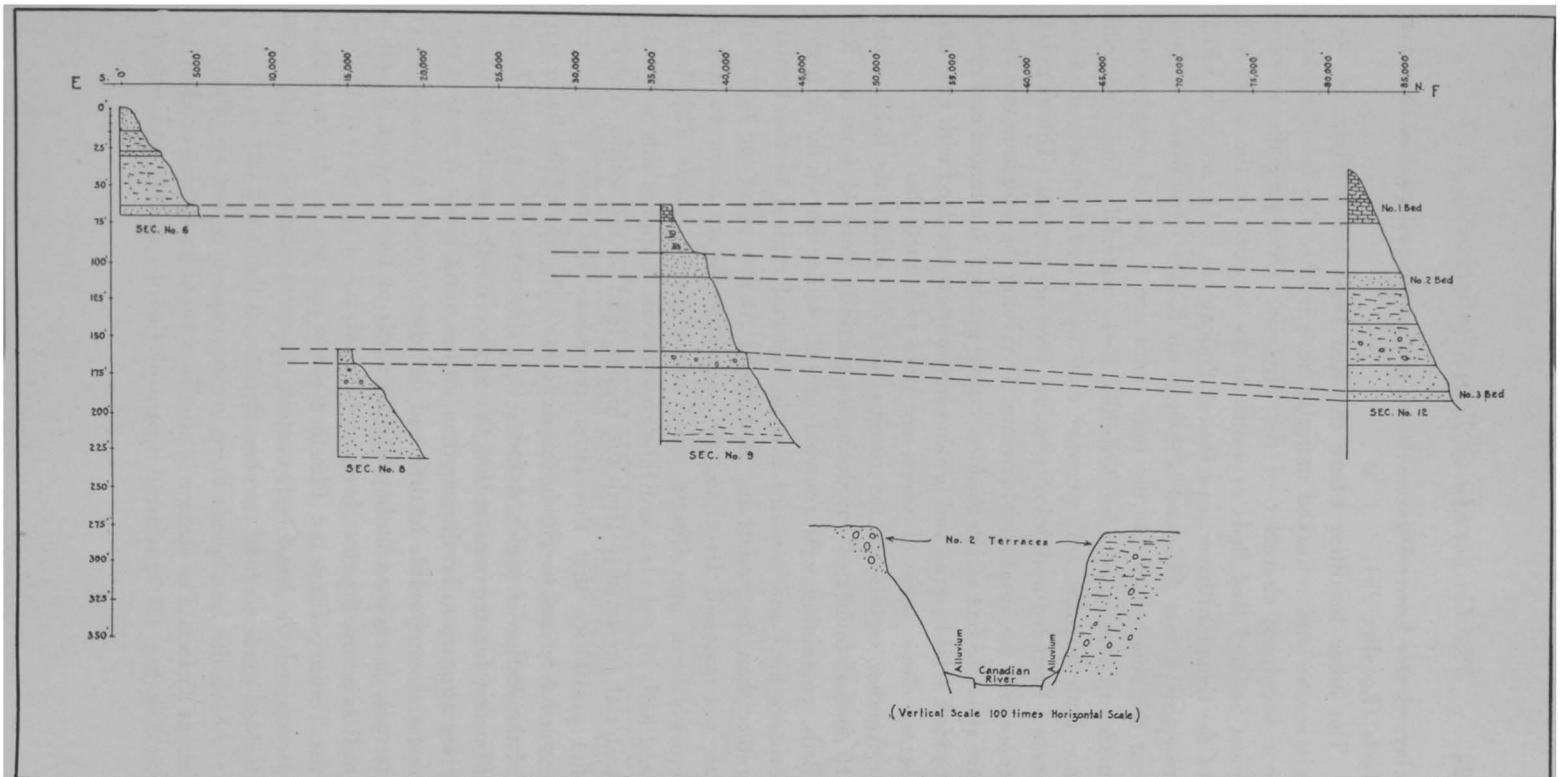

Fig. 5. Sections of Lower Pliocene along line E-F, Hemphill County, Texas.

clay. A few Lower Pliocene horse teeth were collected in the basal beds (Locality 25).

The other localities where the Red Beds are overlain by conglomerates and reworked material have neither the fossil evidence nor lithologic character of the Pliocene. Overlying the westernmost isolated Red Beds exposure at the locality on the south side of the Canadian River, east line of Coördinate K-11, are beds which resemble Lower Pliocene, although no fossils were found to bear out the conclusion. At the base there are 2 feet of conglomerate made up mostly of reworked Red Beds material. The fragments are both angular and rounded clay balls and boulders of sandstone. Rounded nodules of powdery lime are present. This material represents the basal conglomerate. Overlying the conglomerate there are about 15 feet of interbedded, coarse-grained, laminated and cross-bedded, friable, gray and brown sandstone interbedded with gray and brown clays, some of which are pure and unctuous.

Another section, in the eastern part of Coördinate L-17, shows 10 feet of indurated conglomerate partially derived from the Red Beds, containing well rounded gravel, while the whole is highly cross-bedded and contains a little material typical of the Tertiary rather than the underlying Red Beds. At this point the Red Beds are not exposed. Overlying the conglomerate are about 40 feet of cross-bedded, prevailingly gray, coarse-grained sands with lenses and balls of red clay and lime concretions. Capping this is detrital material presumably from the higher land to the south. There is the possibility that this latter represents the base of the very extensive terrace overlying this exposure. The age of the lower part of the section is also unknown. It is shown on the map as Lower Pliocene for the reason that the terrace on the south side of the river appears to be thinner than on the north side. A section with material comparable to this, and definitely proved by fossils to be terrace, is exposed at Locality 28 north of the Conatser Ranch as well as across the river from it. It is difficult at places to distinguish the Tertiary from the Pleistocene terrace, but as far as can be ascertained, the basal beds contain no unconsolidated, highly cross-bedded sands such as are characteristic of the No. 2 terrace.

Above the basal beds there are no exposures for an interval of about 35 feet. The surface is usually covered by terrace or alluvium. At Locality 13, northwest corner of Coördinate J-6 and near the

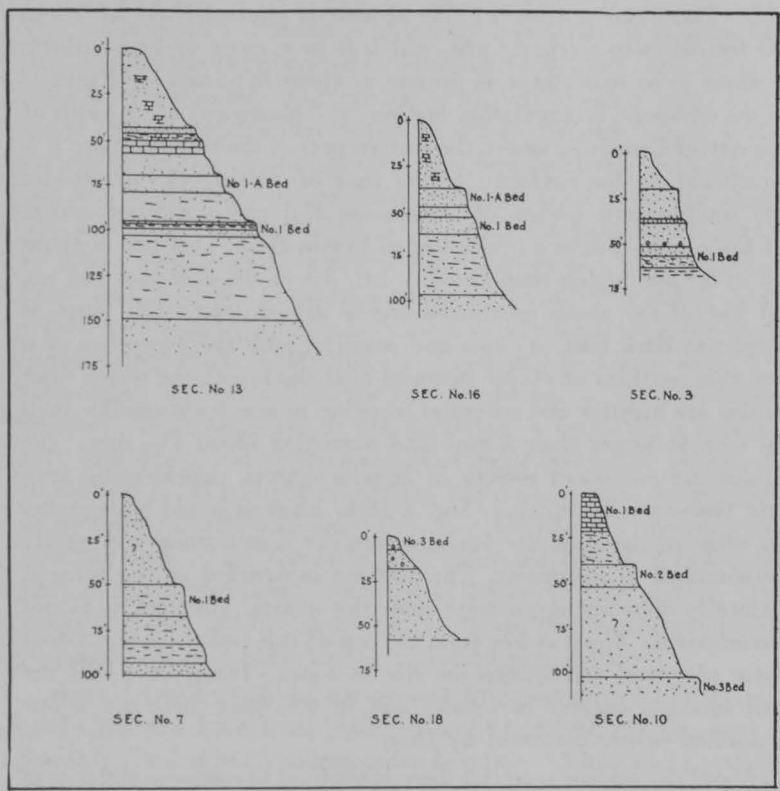

Fig. 6. Miscellaneous Lower Pliocene sections, Hemphill County, Texas.

junction of the Canadian River and Red Deer Creek, there is a small exposure showing about 16 feet of friable, very coarse-grained sandstone of gray-brown color. This outcrop is estimated to be about 35 feet from the base of the Tertiary. The next exposure is about a mile north of this at Locality 14. The latter place is approximately 80 feet higher stratigraphically than Locality 13. At the base of the exposure are 10 feet of white to greenish limy sand overlain by 20 feet of brown clay interbedded with brown silty sandstone. It is in the lower portion of this section that the fossils of Locality 14 were found. Above this exposure there are several outcrops of brown sandy clay present in the divide between Red Deer Creek and the Canadian River up to the long section (Section 11) measured at Triangulation Station "F" in Coördinate

H-5. The basal portion of this section is characterized by about 60 feet of coarse arkosic grit, which is in a more or less uniform horizon in as much as it is present at about the same level farther to the east near Triangulation Station "E," about 3½ miles south of the city of Canadian, and in the eastern part of the county where it is weathered on the surface. At the base of Section 11, situated in the southwestern corner of Coördinate H-5 and northwest corner of Coördinate J-5, is a 5-foot bed of brown clay. This bed is about 15 or 20 feet higher than Locality 14. Above the thin clay bed are 60 feet of the above mentioned coarse arkosic grit. The latter is brown to dark buff in color and massive, with the exception of a few thin partings of clayey material near the top of the series. The grains are angular and irregular, ranging in size from smaller than ½ mm. to larger than 3 mm. and averaging about 1½ mm. The grains are composed mostly of angular quartz, considerable gray and flesh-colored feldspar, and a little magnetite and phlogopite. In some of the beds the feldspar is quite conspicuous and nearly as abundant as the quartz. The feldspar is rounded on the corners, naturally showing more wear than the quartz, although it is not decomposed. About 5 feet from the top of this bed there is a 1-foot layer of gravel with grains the size of a pea. Toward the base the grit becomes coarser in texture and in this part there are a few indurated layers cemented by lime.

Above the arkosic material there is medium to coarse-grained sand in a massive 6-foot bed. The material is dark brown in color and contains a little clay as well as a few lime nodules, and is overlain by a 3-foot bed of brown clay mottled with green. It contains a little grit and numerous lime concretions. Above this is an unstratified 5-foot bed of coarse irregular-grained sand in a matrix of red-brown clay. It contains an abundance of lime nodules which toward the top constitute about half of the material. The bed caps the zone of coarse sand or arkosic grit. There are no arkoses of so coarse a texture higher in the section.

The next bed in the section is a 32-foot massive red-buff sand, which is medium-grained and contains a little clay and numerous lime nodules. Overlying it are 6 feet of dark brown clay with little or no gritty material but a few lime nodules. The next in the series is a 22-foot bed of massive loess-like sand of reddish to buff color.

The lower portion contains a little clay as matrix. It is quite soft but nevertheless weathers in a perpendicular bluff, this being a marked characteristic of these sands and some other beds in the upper part of the series below the No. 3 bed. Several of these sands, including the last mentioned bed, have been analysed mechanically and will be discussed in connection with the origin of the sediments. The next higher divisible bed, which has a thickness of 15 feet, is in reality similar to the one just described but is a little lighter in color and the sand grains appear to be finer. Next above is an 8-foot bed which, near its base, contains blocky-weathering sandstone about 1 foot thick showing fine laminations. In places there is a continuous induration from the base to the top of the next higher member. Where this bed is not indurated, it would be a massive, soft, buff sand. The uppermost bed of this basal series, as exposed in Section 11, is a slightly resistant and massive sand 4 feet thick. It contains considerable secondary lime as stringers and also soft powdery lime. This bed is usually indurated and of a buff color similar to the two beds immediately below in this section. The contact of this and the overlying No. 3 key bed is unconformable at places, but as a rule there is a gradual gradation.

Several fossil localities are present from which mammalian and turtle remains have been collected and identified. At the base is Locality 25, and in ascending order Localities 13 and 14. Localities 21, 9, 11, 10, 1, 2, 3, 5, and 16 are at the top and in places extend upwards into the No. 3 key bed of the lower beds group. These last localities are by far the richest in fossils.

Lower Beds.—As may be seen from Figure 2, this lower beds group is 140 feet thick and occupies a relatively high position in the Lower Pliocene column. In the western part of the county it is distributed around the mesas and escarpments, and in places extends to form a low escarpment toward the valleys and east of the higher mesas. There are two indurated beds included within this group, the No. 3 and No. 2 beds, and these are somewhat similar in lithology, although the uppermost bed pinches out in the extreme western part of the county and is not indurated throughout its entire outcrop, while the lower is prevailingly uniform.

The lower of these indurated beds is from 5 to 25 feet thick and is one of the most persistently indurated and widely distributed of

the key beds used in mapping. In lithology this bed is a more or less massive, gray, friable sandstone which contains a little gravel. It is well defined, being overlain and underlain by massive buff sands which are in contrast with its gray color. The overlying buff sand is from 15 to 50 feet thick and is covered by clay extending up to the No. 2 key bed. In a few places loose sand and gravel replace the clay and varying amounts of underlying buff sand.

The No. 2 key bed is a gray, laminated, friable sandstone of 10 to 25 feet in thickness, containing some gravel and clay pebbles, as does the No. 3 bed, but the latter is seldom laminated. Overlying the No. 2 bed up to the top of the lower beds group is a bed of brown clay which in places becomes sandy.

In the lower portion of this lower beds group, although less plentiful than in the groups below and above it, there are considerable vesicular lava boulders associated with the gravel and gray sands. Some of the lava pieces are 2 or more feet long and are "bread-crust" bombs, probably transported (mainly) by flotation. The prevailing size, however, is from 3 to 6 inches in diameter.

In Section 1, south portion of Coördinate O-1, in Roberts County, the bed immediately below the No. 3 key bed is composed of 38 feet of brown sand. It is laminated and cross-bedded, especially in its lower portion where it is less indurated than higher up. There are pockets of gravel and balls of clay scattered through it, and in the uppermost portion there are calcareous nodules. Just above this there are 6 feet of gray to brown, friable, calcareous sandstone which is the No. 3 bed. The bed overlying is not well exposed at its base, but the upper portion is composed of massive soft buff sand with many lime nodules.

At Section 5, western portion of Coördinate N-2, Roberts County, the lower limit of the No. 3 bed is vague, and the whole has been described as gray to brown, soft, friable sandstone of fine and coarse grain. It contains gravel and balls of white limy clay and interbeds of white clayey material. The lower portion weathers to a soft buff sand and in places to white caliche-like beds, but the upper portion is a more definitely uniform bed of friable sandstone, here restricted to the No. 3 bed. The whole is 30 feet thick. Overlying it are non-resistant beds, poorly exposed, but their upper portion

shows a soft buff sand with lime nodules with a total thickness of 80 feet.

In Section 8, above the middle part of the west line of Coördinate M-3, there are 45 feet of soft brown or buff sand containing numerous lime nodules. This is overlain by the No. 3 bed, which in its basal portion is bedded and cross-bedded and contains a little gravel, while in the upper part, which is called the No. 3 proper, the sandstone is massive and friable with less gravel. At this point the bed is abnormally thick and all of the cross-bedded sands may be put into one bed.

Section 9, on the south line of Coördinate J-3, shows about 50 feet of massive buff sand with lime nodules and a little brown clay near its base. Overlying it is the No. 3 bed with a thickness of 10 feet. It has the characteristic gray color and contains a little gravel. Section 10, on the east line of Coördinate J-2, shows the upper portion of the No. 3 bed exposed and overlain by about 50 feet of massive buff sand. In Section 11, in the northwest part of Coördinate J-5 and southwest part of Coördinate H-5, the beds underlying the No. 3 bed have been previously described. The No. 3 bed at this point is 5 feet thick and is composed of medium-grained, gray to buff, friable sandstone weathering into a definite ledge. Overlying are 14 feet of massive reddish-buff sand with lime nodules near the base. Section 12 is in the northwest corner of the county in the eastern part of Coördinate D-2. In this area the No. 3 bed is poorly exposed and for only a short distance. The base of the exposure shows 6 feet of the No. 3 bed as a medium-grained, gray, friable sandstone containing a little gravel and small white clay balls, but near the base both the gravel and clay balls are abundant. Above this are 17 feet of soft buff sand with gravel at or near the base. Section 18 is in the southwest corner of Coördinate M-4. At the base of the section there are 40 feet of soft buff sands with lime nodules and a little clay, overlain by 11 feet of laminated and bedded friable sandstone containing lime nodules and white clay inclusions. This may be the lower portion of the No. 3 bed, but it is not resistant, or characteristic of that bed. Above this is the No. 3 bed proper with a thickness of 8 feet. It is a faintly-bedded, gray-buff, medium-grained, limy, friable sandstone projecting as a prominent ledge. White clay pebbles and a few lime nodules occur

in this bed. Gravel is on the talus slope and probably comes from the base of this bed and the one underlying it. The No. 3 bed here caps the mesa. Section 19 is on the west line of Coördinate N-4. Here the section below the No. 3 bed is a little different from that at other localities. At the base there are 18 feet of massive, reddish-buff, soft sand with abundant lime nodules, above which are 12 feet of loose, brown, coarse-grained sand probably with some gravel. Overlying this are the 2.5 feet of brown clay, which is limy near its top. Capping this is the indurated sand of the No. 3 bed with a thickness of 17 feet. It is buff in color, medium-grained, and at the base there is a 1-foot bed of clay balls and gravel, as well as a little gravel in the sandstone itself. Section 20 is in the northeast corner of Coördinate M-5. The No. 3 bed which is exposed at its base is 15 feet thick with more than the usual induration. It is a gray, limy, friable sandstone composed of medium grains and having faint bedding-planes. Above is the usual exposure of massive red-buff sand with lime nodules measuring 45 feet in thickness at this point.

From the above sections it may be seen that the No. 3 bed is quite different from those immediately above and below it, and that these beds have a fairly uniform character which may be recognized wherever they are exposed. The actual thickening of the No. 3 bed is probably greater than is shown on the cross sections as induration was the chief criterion in the vertical limitation of the bed at that point. As in Section 18, the bed immediately below the No. 3 bed could be placed in the same bed with it, and that is the case in Section 8 and in several others. Under another topic the origin of the various beds will be discussed, but it may here be stated that the No. 3 bed was not formed in the same manner as the beds above and below it. Near Locality 10, Coördinate J-3, the base of the No. 3 bed shows an unconformable surface with a wavy plane of contact resting on massive buff sands. Above the contact there are small lenses and pockets of white, limy, sand-pebbles. At another place, along the east line of Coördinate K-3, the No. 3 bed is composed of about 50 per cent of small, white, clay pebbles, and this condition extends for at least a short distance to the north. In the north-eastern corner of Coördinate L-6, the No. 3 bed is 20 feet thick and is most indurated in its upper portion. Where it is exposed

in the canyon it is overlain and underlain by red-buff massive sands bearing numerous lime nodules. The bed is unconformable with a wavy contact upon the buff sand. The lower portion contains some gravel, both large and small, and a number of small, reworked sandy lime pebbles are contained within it as streaks or thin lenses. There is an assortment of sand grains in steeply inclined lenses. The contrast of the gray-buff No. 3 bed and upper and lower red-buff beds is quite conspicuous.

The massive buff or reddish-buff sand with lime nodules which overlies the No. 3 bed is a fairly constant horizon as displayed in most of the measured sections and observations in the field. The normal thickness of this bed is 50 feet, although in Section 5 it is 75 feet and in Section 12 only about 15 feet. In the latter section the upper portion of this bed is replaced by about 15 feet of loose sand with gravel, clay balls, and lenses of clay. This is also the case in an exposure near Triangulation Station "I" in the western part of the county about 1200 feet east of the west boundary and just south of the Canadian River, where there are just a few feet of the buff sand above the No. 3 key bed succeeded by loose sand with gravel. It has been noticed that this loose sand which replaces the massive buff sand is prevailingly gray and occasionally brown, but never of red-buff color. An inspection of the plotted sections will show the relations of these sands. On the southeast side of Red Deer Creek the massive red-buff sand is abruptly overlain by brown clay. In places this clay is sandy in thin layers, the sand being very fine or silty, and in a few other places is pure and unctuous. Near the county line this clay bed has an unbroken thickness of about 30 feet, but to the northeast the bed thickens and becomes sandy in the middle, until in the northeast part of the line of Section "A-B" a definite sandstone bed forms. This is the No. 2 key bed. On the northwest side of Red Deer Creek the above mentioned clay is absent, as may be seen in the southwest part of Section "C-D." In the northeast part of this cross section the No. 2 bed comes in, and it is possibly present in Section "E-F." The clay evidently replaces the upper part of the massive red-buff sand on the southeast side of Red Deer Creek with a thickening on the northeast. In Section "C-D" a small amount of sandy clay is seen capping the red-buff sand, but to the northeast, with the exception

of Section 11, it is absent. The No. 2 bed is a more or less persistent sandstone, occurring in this section about midway between the No. 3 and No. 1 key beds. In the extreme western part of the county this bed is not present, and, as the sections show, it comes into prominence about 5 miles from the county line and extends eastward between the other beds as an indurated layer.

At Section 9, central portion of the south line of Coördinate J-3, the key bed No. 2 is exposed in a thickness of 16 feet. It is composed of fine to medium-grained friable sandstone, cross-bedded and lenticular, with clay balls and clay lenses. The color of the beds is gray to buff. At this point it appears to contain no gravel, although there is a little in exposures a mile or so to the south. This bed is immediately underlain by the red-buff sands which extend down to the No. 3 bed. Here it is 50 feet thick and, although soft, it forms a precipitous bluff in the canyon. There is an abundance of lime nodules present. Above the No. 2 bed at this point there are 33 feet of poorly exposed material which from its weathered appearance seems to contain considerable caliche. In Section 11, northwest corner of Coördinate J-5 and southwest corner of Coördinate H-5, the No. 2 bed has a good exposure in the mesa. It is 6 feet thick at this point and is composed of finely laminated, gray to buff, friable sandstone. The induration does not continue for the entire distance around the mesa of Triangulation Station "F." The underlying bed has replaced the upper portion of the massive red-buff sand overlying the No. 3 bed. The bed appears to have been formed by channeling, as it is composed of loose, medium-grained sand with an occasional indurated ledge which is not very hard. The color of this material is light buff to light gray with a few streaks of dark brown sand. The lower 15 feet contains a great deal of gravel scattered throughout the sands. The pebbles are on an average about the size of an egg, although some attain a size of 6 inches in diameter. They are all well water-worn and composed principally of metamorphic, igeneous, and sedimentary materials. Numerous bone fragments are present in this bed and most of them are likewise water-worn. This entire bed is 35 feet thick. Overlying the No. 2 bed at this point are 6 feet of finely laminated, soft, buff sand somewhat similar to that of the No. 2 bed but not indurated. Overlying this are two thin beds composed

principally of clay. In an exposure near the base of the mesa at Triangulation Station "I," central portion of Coördinate H-2, a channeling condition similar to that at Section 11 is present, except that the entire thickness of the massive red-buff sand overlying the No. 3 bed has been removed, and in its place there is deposited at least 10 feet of loose sand with considerable gravel, overlain by 10 or more feet of very friable sandstone. This bed extends nearly up to the No. 2 bed. In the gravel there are numerous bone fragments, some of which have been water-worn. It is true also that the indurated part of the underlying No. 3 bed is considerably thinner in its indurated part at this point, and it is possible that a portion of its upper part was removed along with the massive red-buff sands. The above mentioned gravels are not present a mile south of this exposure. In Sections 21 and 22, in the northeastern portion of Coördinate M-6, the No. 2 bed is present as a semi-indurated bed underlain by brown clay and overlain by brown sandy clay, and in Section 21 by a little caliche, as may be seen from Section "A-B." In Section 20, northeastern corner of Coördinate M-5, the No. 2 bed has a thickness of 8 feet and is friable sandstone, gray in color and of local induration. It is underlain by 27 feet of brown clay with possibly some interbeds of sandy clay. There are some platy layers of indurated silt present. This clay rests directly on the massive red-buff sand. Overlying the No. 2 bed at this point are 45 feet of clay interbedded with sandy clay with a few streaks of secondary lime near its top. The No. 2 bed is not present to the southwest and apparently comes in near this section, as may be seen from the Section "A-B." In Section 12, in the eastern portion of Coördinate D-2, in the northwest part of the county, the No. 2 bed has a thickness of from 10 to 25 feet and is composed of gray to buff, medium-grained sand. It is bedded, laminated, and cross-bedded, and contains large pieces of gravel and small white clay inclusions. It weathers into rough layers and is cavernous. Below this bed there are 23 feet of gray-brown, fine, sandy clay, which is underlain by 27 feet of buff sands containing partings of gravel as well as clay balls and interbeds of brown clay. There are also aggregations and nodules of lime. It appears that this bed, by some agency such as stream channel and valley filling, has replaced all except 15 feet of the massive red-buff sand overlying the No. 3 bed. Section 10,

in which the No. 2 bed is 12 feet thick, is on the east line of Coördinate J-2. This bed is a light gray to light brown sandstone and quite friable. In this vicinity the induration is local and at this point it weathers into caverns. Below this bed there is an interval of 50 feet, which is only poorly exposed, but from all indications it is a massive red-buff sand. Above the No. 2 bed there are 20 feet of alternating hard and soft layers, the harder being due to caliche in thin layers. The softer layers are a buff silt or silty sand with some clay.

On the whole the No. 2 bed is quite similar to the No. 3 bed and the two could easily be confused if their stratigraphic succession were not considered. Both have about the same light gray to light buff color and about the same thickness, but the No. 2 bed is frequently laminated and cross-bedded while this feature is not common in the No. 3 bed. Both of these beds contain a small amount of gravel, but that in the lower bed is more abundant. Their textures are about the same and the sand grains are from medium to fine. The induration and areal extent of the No. 3 bed are more extensive than of the No. 2 bed and more vertebrate fossils have been found in it.

In the Section "A-B" on the southeast side of Red Deer Creek, the southwest portion of the section shows that the upper part of the lower beds series is composed of clay with a little fine sand. In Section 17, northwest corner of Coördinate O-4, the beds immediately underlying the No. 1 bed are as follows: (a) 8 feet of brown clay grading up to (b) 6 feet of brown silty clay with thin plates of indurated silt; (c) 15 feet of brown clay as in (a). In Section 14, the section immediately underlying the No. 1 bed shows 34 feet of brown clay interstratified in 2-foot layers with very silty clay. In Section 5, western portion of Coördinate N-2, the section immediately below the No. 1 bed is not well exposed, but it is probably buff sand with a little clay in its upper portion. In section 1, southern part of Coördinate O-1, overlying the massive red-buff sand and underlying the No. 1 bed, are 16 feet of gray-brown, very fine, sandy clay, parted by lenses or beds of clay, laminated in places and streaked with lime. The base is not seen, so this bed may actually be thicker than represented. In Section 11, northwest corner of Coördinate J-5, the strata underlying the No. 1 bed are 27 feet thick and composed of interbedded gray-brown clay and sand. The clay

contains considerable lime in the form of nodules and stringers, while the sand contains lime nodules only. The very top bears a great deal of lime, and this grades up to the No.1 bed. In Section 13, in the southern part of Coördinate N-4, underlying the No. 1 bed, there are 45 feet of gray-brown, very fine, sandy clay and clay, in a poor exposure, and in Section 16 there is the same sequence.

The lower beds group contains several fossil localities which were mentioned in the discussion of the basal beds group, and higher in the lower beds group are Localities 3-A, 22, 12, 15, 18, and 20, the last two of which may be placed in the base of the middle beds group.

Middle Beds.—The middle beds group comprises only two beds, the No. 1 key bed and the strata overlying it. These have a combined thickness of about 25 feet. The No. 1 bed varies more in lithology than any other in the Lower Pliocene. It is composed locally of volcanic ash, limy sandstone, friable sandstone, chalcedony, and caliche, at various places within the county. Its color is prevailingly white on account of the lime and clay it contains. It forms one of the most persistent of the mappable units, and outcrops in the western portion of the county where it caps the next to highest escarpment and mesas. This bed has an average thickness of 10 feet. Overlying it are about 15 feet of brown sandy clay.

In Section 14, southwest quarter of Coördinate O-4, there is a typical and probably the best exposure of the No. 1 bed; it is here from 8 to 10 feet thick. In places it is one bed, but it is usually parted by a clay layer. It ranges in color from white to light gray and is a fine-grained, calcareous sand which is firm and forms a conspicuous bed even though it is not indurated. There are in places small balls of clay and a few large sand grains, while in some places there are faint laminations. It is underlain by a thick clay bed and overlain by 22 feet of fine-grained limy sand, reddish in color except at the base, where it is light gray. It is massive and shows no bedding. In places in this exposure the lower 5 feet are composed of sandy clay which is cross-bedded and in wave-like folds. This is probably a fossil quicksand bed. In Section 15, central portion of Coördinate P-2, the No. 1 bed has a thickness of 10 feet and the same lithology as in Section 14. Overlying it are 16 feet of medium to coarse-grained, loose, light-colored sand containing a little gravel and clay balls, especially near the top. In

Section 17, northwest quarter of Coördinate O-4, the No. 1 bed is divisible into the following: (a) 5 feet of pinkish-gray firm sand, unevenly laminated; sand grains medium-fine; some very small clay pebbles; a little light gray clay at base; (b) 1.5 feet of white limy clay possibly containing a little volcanic ash; (c) 12 feet of material similar to (a). Both (a) and (c) are limy. In this section the No. 1 bed is thicker than usual. It is overlain by 16 feet of brown silty clay. In Section 13, southeast quarter of Coördinate N-4, the No. 1 bed consists of the following sub-divisions: (a) 4 feet of limy light gray clay and pinkish-colored sand; (b) 3.5 feet of light buff to light greenish, very fine-grained sandy clay which weathers more readily than the other members; (c) 2 feet of material similar to (a). This bed is overlain by 16 feet of brown sandy clay. In Section 2, northern part of the east line of Coördinate P-2, the No. 1 bed is somewhat similar to the exposures given above. In Section 1, southern part of Coördinate O-1, the No. 1 bed is 18 feet thick and composed of massive and relatively resistant sandy clay whose layers alternate in color between white and pinkish-brown. The whole contains considerable lime. Above this are 20 feet of coarse sand with gravel. The above description gives the normal characteristics of the No. 1 bed where it is covered by an overburden of sediments, but to the east, as may be seen in Section "A-B", the bed loses its usual characteristics and becomes a definite bed of caliche capping the mesas and escarpments. The caliche seems to have been formed more or less in the zone of this bed, but frequently it is seen to extend a short distance below as well as above. This is also true in Sections "C-D" and "E-F".

In Section 5, western portion of Coördinate M-2, there is an interesting development of the No. 1 bed. It is 10 feet thick below Locality 6, and is composed of white limy sand which possibly contains a little volcanic ash. Here it is in a firm unindurated bed, but ½ mile to the north, on a small hill, it is a very hard and brittle chalcedony which has a brecciated texture. It was seen that the No. 1 bed at Section 15, central part of Coördinate P-2, is about 10 feet thick and has about the same characteristics as the usual unaltered exposure. From this point to the northern part of the Coördinate there is a marked change, for, as the outcrop is followed to the north, the bed above the No. 1 bed is seen to thin as the latter thickens, while its lower part presumably remains the same, and the

upper part becomes a conglomerate and weathers into a quartzite-chalcedony conglomerate or breccia of great hardness. This is best developed on the county line where the outcrop swings east. The upper indurated portion at this point is about 5 feet thick and the overlying bed is entirely absent, bringing the No. 1 bed and the No. 1-A bed into contact. A short distance south of this, where the induration is not so well developed, the upper portion of the No. 1 bed is composed of a conglomerate of rounded and angular pieces of white material about the size of an egg. Where indurated, the boulders and the matrix show different colors and textures, giving to the upper portion of No. 1 bed a conglomeratic appearance. This chalcedony material is the same as that found in Section 5. These occurrences of chalcedony are local. At Locality 20, west line of Coördinate P-3, there is an exposure which shows the No. 1 bed to be composed principally of volcanic ash. At the base there are 3½ feet of light gray-green, fine sand in a clay matrix overlain by 2 feet of light gray-green clay. Above this there are 10 feet of volcanic ash, the lower portion of which is fairly pure, while the upper portion contains considerable lime. This is exposed for a distance of only 500 feet, and ½ mile to the north there is a normal exposure of the No. 1 bed. Above the No. 1 bed there are usually about 15 to 20 feet of brown sandy clay, but in one or two cases, as at Sections 1 and 15, loose sand with gravel occupies the interval between the No. 1 and No. 1-A beds. It is also the case that to the east the bed overlying the No. 1 bed contains considerable poorly developed caliche.

Fossil Locality 20, which was quarried, may be considered to be in the base of the No. 1 bed rather than in the top of the lower beds group.

Upper Beds.—The distribution of these upper beds is confined to the western part of the county where the land is highest. The No. 1-A key bed, which is at the base of the group, forms the highest recognizable bed in the Lower Pliocene series, and is more or less a cap for the plains in this area. The overlying bed forms an overburden which in places attains a thickness of over 75 feet. The No. 1-A bed has a thickness of about 10 feet, and in its unaltered exposures is a gray friable sandstone of about the same character as that of the No. 2 and No. 3 beds. The usual exposure is caliche.

The overlying bed extends to the top of the plains and is composed of fine buff sand with interbeds of clay and is generally highly impregnated with caliche. Locality 6 is in the horizon of the No. 1-A bed and Locality 19 is a little higher up. It is possible that the very uppermost part of the section, that above Locality 19, is younger than Lower Pliocene.

In Section 15, central part of Coördinate P-2, the No. 1-A bed has a thickness of 8 feet and is composed of irregularly-sized grains in a gray to buff friable sandstone which is faintly laminated and contains a few clay inclusions. In Section 2, along the north portion of the east line of Coödinate P-2, this bed appears to be absent in the section but comes in again, as may be noted on the Section "A-B." In Section 14, southwest corner of Coördinate O-4, the No. 1-A bed is about 10 feet thick, the basal 2 feet being a limy, silty clay overlain by a faintly-bedded, friable, limy sandstone of fine to medium grains and gray to buff in color. There are a few partings of sandy clay within this bed.

At Section 17, northwest quarter of Coördinate O-4, the No. 1-A bed is 10 feet thick. At the base there are 2 feet of clay balls within a sandy clay. The remainder of the bed is a laminated and cross-bedded, friable, limy sandstone containing clay pebbles. Above this bed and to the top of the section there are 10 feet of fine-grained, buff, limy sands with considerable caliche. At Section 13, southern part of Coördinate N-4, there are 10 feet of light gray to light buff, fine-grained limy sand which in places is almost white. At the top there is a thin layer of caliche and at the base a nodular caliche bed, probably an impregnation, about 1 foot thick. The No. 1-A bed is 10 feet thick at this point. This section is overlain also by fine-grained buff sands impregnated with caliche. In Section 1, south part of Coördinate O-1, the probable equivalent of the No. 1-A bed is No. 8 of the section. This bed is 20 feet thick and is composed of coarse-grained friable sandstone containing a little gravel and clay balls. The induration is irregular, but it may be traced for a distance of several miles to the north and east. Above this bed there are about 80 feet of fine-grained buff sands impregnated with lime and caliche layers which form the top of the plains. The southwest part of the county is extensively capped by a caliche phase of the No. 1-A bed overlain by 50 or more feet of limy buff sands.

UNDIFFERENTIATED LOWER PLIOCENE

There are two areas within the county where correlation was not possible and these have been placed on the map as undifferentiated Lower Pliocene. The first is a relatively small area about 5 miles north of the town of Canadian. As indicated on the map, there is an outcrop of one bed which may be followed for over 2 miles and this is the only bed exposed. It is probable that it is the No. 2 bed appearing in the northwest corner of the county, but it cannot be traced through. The bed is 10 feet thick and is composed of gray friable sandstone which is somewhat laminated. The other area, also of small extent, is in the extreme northeast corner of the county. This also cannot be correlated with the beds in the western portion of the county. Its relatively low elevation would make it appear to be nearer the zone of the No. 3 bed than the No. 1. A section in the southwest corner of Coördinate C-18 shows 20 feet of fine-grained, massive, buff sand highly impregnated with lime nodules and overlain by 18 feet of dark buff, massive, loose sand of coarser grains than the lower bed. This grades up into 10 to 30 feet of caliche which is soft at the base. A sample of the middle bed has been analysed mechanically and is described as Sample No. 1 From what has been observed of the exposures in this area, the section appears to be quite variable, but throughout the area there is a heavy cap supporting the mesas. On the south line of Coördinate C-17, the caliche cap contains a large amount of siliceous matter which resembles chalcedony. At this point underlying the siliceous "caliche"[1] cap there is a bed of white limy sand which is in turn underlain by loose buff sand. At another point, about 1 mile north of Commission Creek in Lipscomb County, a thick bed of red-brown clay was noted. Beds of light gray limy sand and reddish sands are common in the interval below the cap rock. Slumping on a large scale in this area adds to the confusion of local correlation.

LOWER (?) PLEISTOCENE

Terrace No. 1.—The No. 1 terrace is found on the south side of the Canadian River just east of the town of Canadian and occupies only a relatively small area. It is differentiated from the others

[1]No better term is known for a deposit of siliceous material by the same process of evaporation as in the deposition of true caliche.

because it is about 25 to 50 feet lower in elevation than the No. 2 terrace, and about 40 feet above the Canadian River flood plain. The only exposure noted is in a gravel pit on the east edge of the town of Canadian. Here there are exposed brown sands, clayey sands and gravel. It is from this pit that a tooth of *Elephas columbi*, Pleistocene in age, was found. So far as could be determined this is the only exposure of the No. 1 terrace, although there may be equivalent remnants of it up the river.

Terrace No. 2.—The No. 2 terrace is exposed on either side of the Canadian River as is indicated on the geologic map. This terrace is composed of loose brown sands (some of which are highly cross-bedded) and gray sandy clays, and is capped by a definite bed of dark to light gray limy sand, which has a distinctive coloring and contains numerous fresh water shells. These are *Pisidium*, *Physa*, and *Planorbis similaris*, as determined by Dr. Junius Henderson.

In the eastern portion of Coördinate L-17, there is an exposure tentatively referred to the basal portion of the terrace, although this may be Lower Pliocene, as suggested under that heading. The exposure shows 10 feet of indurated conglomerate partially derived from the Red Beds and containing well rounded gravel, while the whole is highly cross-bedded and contains a little reworked material that is typical of the Tertiary rather than of the underlying Red Beds. Overlying the conglomerate are about 40 feet of cross-bedded, prevailingly gray, coarse-grained sand with lenses and balls of red clay and lime concretions. Capping this is detrital material, presumably from the higher land to the south. If the lower portion of the section is Tertiary, then the detrital material represents the basal material, but it is now believed that the lower portion of the section is terrace material. This section corresponds to the one which will be described next. Section 29 at Locality 28, western portion of Coördinate J-14, shows a section of terrace material which, in the bottom of the canyon, consists of 20 to 35 feet of loose medium-grained sand and gravel. The sand shows conspicuous top-set and fore-set bedding with gravel on the bedding surfaces as well as in the thin lenses. A few balls of red-brown clay and rounded boulders of grit or arkosic sandstone are present. The upper part is not well exposed. Overlying this is a 15-foot bed,

principally composed of sand; the lower portion is a purplish-brown, laminated, coarse-grained, soft sand mixed with a little clay, while the upper portion is a buff, fine-grained sand, laminated and parted by thin layers of purplish-brown clay. Above this there are 6 feet of light gray clayey sand which shows no bedding. This material contains innumerable fresh water shells, and is the same bed which caps the terrace farther up the river to the west. A great deal of lime is present in this bed, for, in places where it has been exposed, stringers of caliche are present. In places this bed is parted by a 2-foot layer of brown laminated sand. Following this are 3 feet of unctuous, dark red-brown clay mottled with gray. Capping the terrace are 3 feet of massive, coarse, brown sand.

On the north side of the Canadian River, just north of the bridges, there are some 15 feet of cross-bedded gray to brown loose sand. Capping the terrace is the light gray sandy clay, bearing shells, and this is underlain by some gray and reddish-brown sands. In the northwest corner of Coördinate G-6, the top of the terrace is composed of gray sandy clay containing considerable lime, which approaches a semi-indurated caliche. North of the Canadian River, in the western part of the county near the west line of Coördinate F-3, the terrace attains considerable thickness. Near the edge of the alluvium there are soft red-buff sands and a thin bed of red clay, and at the top of the terrace there are exposures of red-brown clays and sandy clays, most of which contain gravel.

Vertebrate fossils, which prove the age of this No. 2 terrace to be Lower Pleistocene, were found at Localities 26, 27, and 28, and at another reported locality south of the Canadian River in Oklahoma.

Terrace No. 3.—The No. 3 terrace is exposed in a limited area north of the Canadian River and about 5 miles north of the city of Canadian. This terrace is not so pronounced as the No. 2 terrace, because it has been eroded and in most places covered by dune sand. It is about 130 feet above the No. 2 terrace. In the northeast corner of Coördinate D-7, which is about the top of the terrace, there is an exposure showing 15 feet of cross-bedded brown sands, overlain by 3 feet of reddish sand, and capped by 2 feet of quartzite gravel. South of this point, and in the northwest part of Coördinate E-8, which is at the base of the terrace, there is an exposure of soft,

brown, coarse sand containing large and small gravel. The thickness of the terrace is about 80 feet. In the uppermost part of this terrace, shells similar to those found in the No. 2 terrace are present, and it is probable that the No. 3 terrace is also Lower Pleistocene.

PLEISTOCENE AND RECENT

Sand Hills and Sand Dunes.—As is indicated on the geologic map, the greater portion of the county north of the Canadian River, as well as the southeast corner, is covered by sand hills and sand dunes. There is also a narrow belt of them on the north side of the Washita River in the eastern part of the county. Within these areas there are several stages of sand dune formation ranging from inactive, dissected dunes to the active, moving ones. In mapping their distribution an attempt was made to confine their limits to those areas which exhibit typical dune topography. With the exception of one cervical of *Alticamelus* (?) found at Locality 17, no other fossil material has been collected from these sands, and therefore no definite age can be assigned to them. However, they are younger than the Lower Pleistocene No. 2 terrace, and some are now in the process of formation. The area of dune sand in the southeast corner of the county is probably as old as any of the other sand areas mentioned above, but the criteria for determining their relative age are meagre. There are only a few places where there is loose sand on the surface, and there are very few blowouts since the hills are covered by a thick growth of scrub oak and a mantle of soil has developed. These dunes have remained stationary for such a long time that stream erosion has altered the characteristic dune topography to some extent, and the area is a series of low rolling hills and valleys, with the dunes more clearly exposed away from the creek valleys. It is believed that most of the sand covering this area originated from a reworking of the underlying beds with some sand blown in from the south.

The belt of sand along the north side of the Washita River is in the form of stationary and semi-active dunes with a few active ones in the river alluvium. These dunes are as high as 30 or 40 feet and have steep loose sandy sides. Their formation is more recent than those in the southeast corner of the county, as they were formed

by sand blown from the river bed as well as by that loosened by the dissecting streams.

On the north side of the Canadian River there are semi-active dunes which have partly obscured the No. 2 terrace as well as some of the Pliocene deposits. For the most part the topography of these dunes is very rugged with a number of blowouts and deep sand on their sides. As may be noted from the geologic map and discussion under the heading of "Physiography," there are few drainage channels within this area. Immediately south of the Canadian River the dunes are related in two ways to the No. 2 terrace. In some places they lie directly upon it, while in others the wind action has gouged the terrace until the tops of the dunes are level with the top of the terrace. The latter probably represents an older stage of development. North of the exposures of the No. 2 terrace, it is believed that the dunes for the most part were formed from this terrace, and still farther north to the county line, the materials were derived from the higher or No. 3 terrace and possibly from the Pliocene beds. In this latter area the dunes are prevailingly low and gentle-sloped with a smaller amout of loose sand along their slopes.

North of the Canadian River, in the eastern part of the county just east of Locality 25, there is an area of active dunes extending for about 3 miles in an east-west direction. This area is about ¾ mile in width and about that distance from the river. It is believed that all of the dunes north of the river were formed by a reworking of the terraces by wind and stream action and by a considerable, if not the greater, amount of sand being blown in from the Canadian River bed. On windy days this action can be observed in great clouds of sand and dust which rise from the river bed.

MECHANICAL MEASUREMENTS

The following list of samples represents nearly all of the beds exposed in Section 11 as well as a few isolated ones. Section 11 may be seen on the northeast end of the cross section along the line "C-D," and its relative position in the Lower Pliocene determined from the composite section (Figure 2). The original intention was to study these samples by conventional procedure of mechanical analysis, but upon further investigation it was realized that the equipment, time, and sufficient number of samples from each bed

were all wanting. The diagrams in Figure 3 show screenings from 10 to 200 mesh, corresponding in millimeters from 2½ to ⅛. A determination of the origin of the material cannot be made from the diagrams, but these show the relative sizes of the sand grains and their proportions. Samples 5, 6, 12, and 17 are water-laid deposits, as determined in the field, and a number of others show comparable graphs.

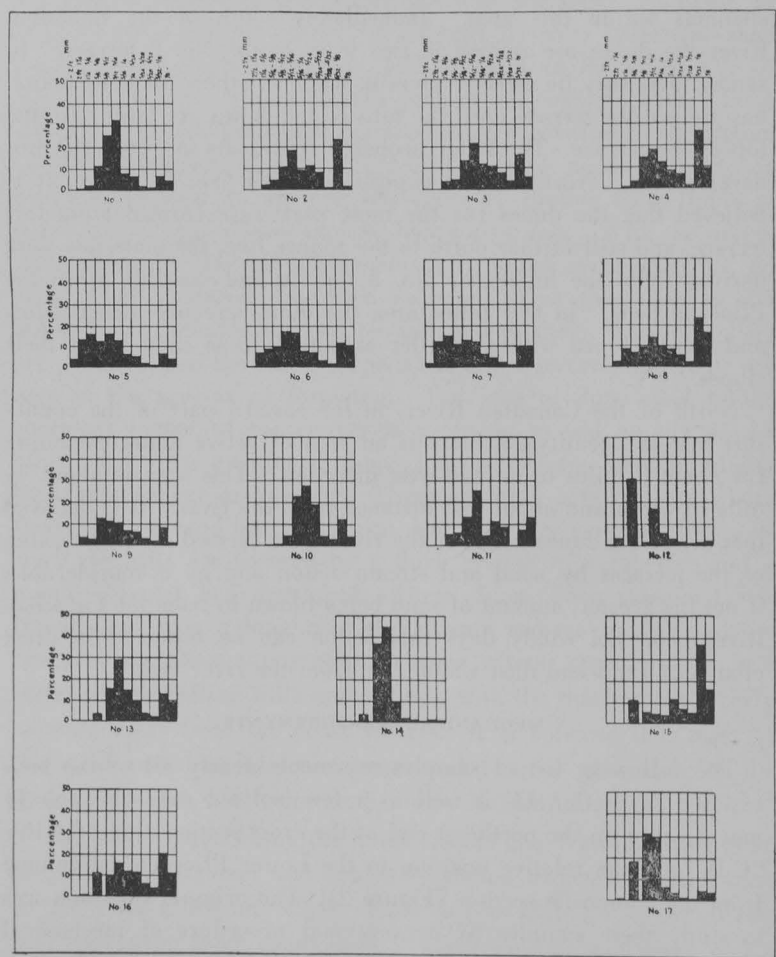

Fig. 7. Mechanical measurements of samples. Diagrams showing screenings of samples of Lower Pliocene beds in Hemphill County, Texas.

LOCATION OF SAMPLES FOR MECHANICAL MEASUREMENTS

Sample—

No. 1. From massive sand bed underlying the cap rock in Section 28, northwest part of county about 5 miles south of Higgins. Southwest corner of Coördinate C-18.

No. 2. From bed 9 of Section 11. Northwest corner of Coördinate J-5, between Red Deer Creek and Canadian River.

No. 3. From massive sand above No. 3 bed. On highway 4 miles south of the city of Canadian. Northwest corner of Coördinate L-7.

No. 4. From Bed 14 of Section 11.

No. 5. From Bed 3 of Section 11.

No. 6. From Bed 4 of Section 11.

No. 7. From Bed 6 of Section 11.

No. 8. From Bed 7 of Section 11.

No. 9. From Bed 21 of Section 11.

No. 10. From Bed 11 of Section 11.

No. 11. From Bed 12 of Section 11.

No. 12. From Bed 15 of Section 11.

No. 13. From Bed 13 of Section 11.

No. 14. From Bed 17 of Section 11.

No. 15. From Bed 18 of Section 11.

No. 16. From Bed 20 of Section 11.

No. 17. From Bed 16 of Section 11.

The above samples were examined microscopically by Mr. C. L. Baker, and the notes on them are as follows:

Sample—

No. 1. Principally subangular quartz with magnetite; some jasperoid chert; no feldspar.

No. 2. Subangular to angular with some dreikanter-shaped grains of quartz, jasper, and magnetite; trace of epidote; some etched grains; more likely eolian origin.

No. 3. Subangular quartz, jasper, magnetite, and phlogopite; may be wind-blown.

No. 4. Same as No. 3.

No. 5. Subangular to angular quartz and feldspar; some magnetite, phlogopite, and biotite; water-laid arkose.

No. 6. Same as No. 5 but with a little muscovite.

No. 7. Same as No. 6 but finer in texture.

No. 8. Same as No. 5.

No. 9. Same as No. 5 but with more muscovite, jasper, and less feldspar.

No. 10. Subangular in texture; mainly quartz with some feldspar and magnetite.

No. 11. Very limy; mostly quartz.

No. 13. Mostly subangular, with quartz the coarser mineral; not much feldspar, if any.

No. 14. Coarser quartz with jasper and chert; a little muscovite; no feldspar.

No. 15. Considerable muscovite, which is more abundant than in any of the other samples described.

No. 16. Mostly aggregates of finer grains.

No. 17. Very largely subangular, but occasional well rounded, etched quartz grains; a little chert and schist; 200 mesh cut very angular.

DESCRIPTIONS OF SECTIONS

	Thickness in feet
Section 1. South central part of Coördinate O-1.	
13. Poor soft caliche to top of mesa	30
12. Sandy caliche; prominent bed	2–4
11. Brown sand poorly exposed	9
10. Sandy caliche	1–2
9. Poorly exposed; brown and white calcareous sand	18
8. Grit or very coarse sand; a little gravel and clay balls; friable; induration irregular, but forms prominent traceable ledge; bone fragments	20
7. Poorly exposed but probably gravel with coarse sand; bone fragments; upper part locally indurated and grading up to Bed 8	20
6. Massive and relatively resistant sandy clay; alternate layers of white and brown; white probably calcareous and not ashy; conspicuous layer	18
5. Gray-brown, very fine, sandy clay; parted by lenses or beds of clay; laminated in places; streaked with lime; base not seen	(exposed) 16
Note: From here up the section is in the mesas back from the creek.	
4. Poorly exposed, but weathered material seems to be dark sand with lime nodules	85
3. Gray to brown friable sandstone; hard in places and occasionally in blocks suitable for building stone; quite calcareous in places	6
2. Brown sand, coarser than Bed 1; laminated and cross-bedded, especially in lower part; soft and not resistant except in upper portion; pockets of gravel and balls of clay; bones found scattered throughout, one, a large front knee joint of greater size than that of a cow. Exposure capped by an indurated but friable, calcareous sandstone; calcareous nodules in upper part	38

		Thickness in feet
1.	Massive sand, forming a perpendicular bluff; free from stratification, although cross-bedding shows up slightly. Brown sand, medium-grained; contains a few pockets of gravel and clay balls; streaks and nodules of carbonate of lime; in places top is indurated, calcareous, friable sandstone. Upon exposure this bed would become very hard	42

Section 2. Northeast part of Coördinate P-2. Measured near the west line of Hemphill County between the Canadian-Miami highway and Red Deer Creek.

8.	Medium-grained, friable sandstone forming prominent ledge; gray to buff in color; more or less massive; contains no gravel or grit (exposed)	22
7-D.	Not very well exposed, but lower portion appears to be similar to that in 7-A. Upper portion contains some finely laminated clays, some gritty clays with material of ash-like fineness; color is chocolate to light gray; streaks and nodules of calcium carbonate in upper portion, especially at top	18
7-C.	Very fine, loess-like sand, rather soft, parted by a 1-foot layer of reddish sandy clay with lime; sand colored gray-brown or buff	6
7-B.	Layer of flaggy sandstone, quartzitic in places; gray in color	3 or 4 in.
7-A.	Not exposed in Section 1. Chocolate-colored (gray-brown on fresh exposure); pure clay; unctuous and free from grit; bed is distinctive although seldom exposed	4
6.	Lower 8 feet fine-grained and resembling loess; finely laminated in places, although appearance from distance is massive. Light gray-brown or buff in color. Whole bed more resistant than Bed 5 of this section. Upper portion pink and white; fine-grained sand containing calcium carbonate; a few clayey streaks. This whole bed is distinctive because of its relative resistance and light color; may contain some volcanic ash	16
5.	Probably complete section. Brown clay, in places unctuous and containing a little grit, while in others a finely laminated silt, but the prevailing aspect is that of a clay. The silty portion is frequently gray. The purer clay appears to be nearer the top in about a 5-foot bed, although it may be irregular	17

Section 3. South central portion of Coördinate N-1.

4.	Same as Bed 3, upper part indurated and forming mesa cap	21
3.	Fine-grained brown sand with lime; massive; lime causes it to be more resistant and it forms a hard outstanding ledge. The upper part does not contain as much lime as the lower	17

Thickness in feet

2. This member has a tentative correlation with Bed 6 of Section 1 and may be subdivided as follows:
   - d. A prominent bed; resistant, white; appears to be composed of sand with a few large grains, caliche, and volcanic ash. In places this has indurated to chalcedony but in most places it has not. This bed has a tendency to indurate even in the area southwest of the valley 1.5
   - c. Unconformable upon lower bed. Fine-grained sand containing considerable lime; light gray to white; reworked pebbles and angular pieces of caliche. Lower 3 feet more typically reworked than upper, but all may be called the same bed. Away from this immediate locality this bed is locally indurated to a prominent ledge 14
   - b. Very fine-grained brown sand, massive and soft 5
   - a. Admixture of sand and clay, unstratified; gray-pink in color and somewhat resembling caliche 6
1. Brown clay, badly weathered. Its appearance is very much like that of Bed 5 of Section 1, and it may possibly be correlated with it ..... not given

Section 4. Western portion of Coördinate N-1.

5. Similar to Bed 4 of Section 3 21
4. Similar to Bed 3 of Section 3 20
3. b. Similar to "d" of Bed 2 of Section 3 ..... 1.5
   - a. White sand apparently mixed with clay, lime, and volcanic ash. Probably corresponds to the white bed at previously described localities 6
2. The lower part is a fine-grained brown sand while the upper part is clay. The whole interval is poorly exposed. The upper part is the possible equivalent of Bed 5 of Section 1 20
1. Indurated in layers, laminated, and parted by soft sand that is not exposed. The sand is medium-grained, with large grains that give it a mealy appearance. Laminations distinctive; gray-brown in color; induration apparently not widespread 5

Section 5. West central part of Coördinate N-2.

10. Same as Bed 9 of this section but does not form a prominent bed, although some of the induration from the lower bed may extend up to it. This is about the top of the mesas in the vicinity of the south line of land Section 32 ..... not given
9. Gray-brown, fine-grained, friable sandstone containing considerable lime. At other localities this bed has a tendency to

Thickness in feet

become caliche. The cap surrounding the mesa at Triangulation Station "U" and other mesas is composed of this sandstone. This bed does not enter into the escarpment in Section 59, although it is probably represented in the plains back from the escarpment. This likewise appears to be true of the escarpment in Section 31 8

8. Unexposed, but probably a soft sandy clay ..... (unexposed) 11
7. Limy, laminated, sandy clay with numerous secondary concretionary layers of lime or material similar to that described from Bed 3 of this section ..... (exposed) 5
6. Composed principally of brown clay. Parted near base by a thin, soft sand layer and a lens of soft sand at 16 feet from base. The latter lens is the horizon at which numerous bones and teeth were collected (Locality 6). Near the middle, numerous secondary strata of lime. It is thought that possibly this member is equivalent to Bed 7 of Section 2 on the south side of Red Deer Creek 33
5. Sandstone, friable; base indurated while upper part soft; fine- and coarse-grained; contains a little gravel 5
4. Medium-grained brown sand containing gravel, clay balls, and bone fragments; loose, but possibly at other localities it indurates 7
3. On one end of the mesa the uppermost part of this member has hardened to chalcedony, very hard and brittle, having a brecciated texture. This bed caps part of the mesa but is not well exposed. From this locality the section was shifted over to better exposures. This bed here shows up to be a white sandy clay possibly containing lime and volcanic ash. In parts it is quite sandy. None of it is indurated because of the fresh exposure. The uppermost cap, a very prominent bed, is composed of chalcedony indurated from the top of this white bed. Here it contains considerable caliche which almost obliterates the chalcedony, but as the bed may be easily traced with the eye, there is no doubt as to the correlation. To the southeast in Section 31 the chalcedony forms the uppermost cap of the mesas. It is believed that the No. 1 bed must contain considerable volcanic ash 10
2. Very poorly exposed on the slope of the mesa but appears to be a soft brown sand with possibly a few sandstone layers. Capped by 6 feet of indurated sand gray-brown in color which forms a prominent ledge on the east side of the mesa 80
1. Gray to brown, soft, friable sandstone composed of a mixture of fine and coarse grains. Contains gravel and balls of white clay (limy) as well as what appears to be interbeds of white material which is probably calcareous. In places the whole

Thickness in feet

bed weathers to a white caliche-like bed, soft with hard nodules. In other places the weathering is to a soft brown sand. It may be that these changes are due to lateral variation in the material instead of weathering, but the exposures are too poor to determine this. Viewed from a distance the bed appears to be white. It is possible that this bed is the same as Bed 3 of Section 1 30

Section 7. Central part of Coördinate N-2.

5. Gray-pink sandstone mixed with clay. Exposures poor and cannot be subdivided. At base a 5-foot ledge; some induration at top; sand exposed as nodules on surface 50
4. No. 1 bed. Sandy and splotched with pink sand; has greater development than at Triangulation Station "P"; thin streaks of chalcedony at top 18
3. Red-brown sand splotched with white sand toward top 15
2. Brown clay 11
1. Soft brown sand. 7

Section 8. West line of Coördinate M-2.

2. Massive-bedded and cross-bedded friable sandstone; gray to brown in color; grains medium and coarse; contains gravel mixed with sand and not as gravel beds; some as large as cobbles, mainly igneous and rounded; columnar weathering in places; of wave-like appearance on top or like horizontal tree trunks; no bones found here; lower 5 feet soft; mesa capped by caliche 27
1. Soft brown-red sand containing numerous sandy lime concretions; massive and apparently weathered 45

Section 9. Northwest corner of Coördinate K-3.

5. Material resembles caliche and lies loose on surface as nodules; capped by caliche which is equivalent to the No. 1 bed. This is better described in Section 10 33
4. No. 2 bed. Composed of fine- to medium-grained, friable sandstone; cross-bedded in lenses; contains clay balls and clay lenses which bear secondary lime; color is gray tc buff 16

Note: This bed was mentioned as being present in Arroyo Washburne valley, but here it plays a more important part since its outcrop is conspicuous around the valley and forms part of an escarpment nearly as complete as the upper and lower key beds. In the Washburne valley it is fine-grained and silty, but here it is considerably coarser and in one or two places was seen to carry gravel.

Thickness in feet

3. Massive buff sand which is indurated, although it forms a precipitous bluff in the canyon; has the appearance of being weathered; poorly exposed but seems to have a clay bed or else the sand contains more clay near base; characterized by an abundance of lime nodules scattered throughout; a few bone fragments noted, although no good specimens obtained 50
2. The No. 3 bed. Similar to Bed 2 of Section 8, but does not contain as much gravel ..... (about) 10
1. Similar to that at Section 8. Contains brown clay near base; poorly exposed 50

Section 10. Central part of Coördinate J-2.

5. This is the highest bed in the vicinity and forms a cap for the plains. This is the No. 1 bed or its equivalent. Here it has induration of 20 feet. More or less massive, white to light brown in color with a great deal of white material toward base. Nearly the whole has turned to caliche. It is possible that the same white material as described in the southern part of the area is again coming in, for north of this section and on the mesas on which Triangulation Station "I" is situated there is a white material of light weight that has a tendency to indurate to chalcedony. Possibly in this northern area the mode of induration and exposure of this upper cap obliterates and prevents recognition of the white bed as noted farther south. Several miles up the Canadian River and west of this area it has been noted that in this general horizon great ledges of rock have been altered to chalcedony. In all respects this seems to be about the same horizon ..... not given
4. Alternating hard and soft layers, the harder being due to caliche in thin layers and the softer a buff-colored silt or silty sand with some clay 20
3. No. 2 bed. Sandstone, white to light brown with cavernous weathering and quite friable; grains medium to coarse; forms an intermittent hard ledge in this valley ..... (about) 22
2. Poorly exposed interval of about 50 feet comparable in every respect to that of Bed 3 of Section 9 ..... not given
1. No. 3 bed. Equivalent to Bed 3 of Section 1 and Bed 1 of Section 5 50

Section 11. Southwest corner of Coördinate H-5. The upper part of section, from Beds 14 to 22, is on the southwest slope of Triangulation Station "F" mesa.

22. Top cap or equivalent to the No. 1 bed in the southern part of the area. Here it is a caliche containing pebbles of brown clay. The caliche is thought to be secondary and

Thickness in feet

obliterates the original material. The cap in the first place was caused by the already resistant bed, and the caliche resulted upon its long exposure near the surface 16

21. Interbedded gray-brown clay and sand. The clay contains considerable lime in the form of nodules and stringers, while the sand contains nodules. Right at the top there is a great deal of lime and this grades up to the next bed 27
20. Sand, reddish-brown, containing a few lime nodules; massive and possibly bearing a little clay as matrix 8
19. Clay, gray-brown, containing numerous lime nodules 5
18. Clay and sand, interbedded, gray-brown; a few streaks of lime; grains fine 7
17. Sand, finely laminated, soft buff in color; similar to Bed 16 but not indurated 6
16. Sandstone, friable, finely laminated; color ranges from light buff to almost white; induration is laterally intermittent. This is the No. 2 or intermediate bed 6
15. Sand, loose, medium-grained, with an occasional indurated ledge which is not very hard. The color is light buff to light gray with a few streaks of dark brown. The whole is rather poorly exposed on account of its softness. The lower 15 feet contain a great deal of gravel scattered throughout the sand. The pebbles are about the size of a hen's egg on an average, although some attain 6 inches in diameter and at other localities there is vesicular lava as large as one's head. The pebbles are all water-worn and are composed of metamorphic, igneous, and sedimentary materials. In the southern part of the area, gravel forms the lower key bed, but here it lies above it. Numerous bone fragments are in this gravel, but most of them are water-worn. This part of the section corresponds to that mentioned as having been found at the base of Triangulation Station "I" mesa. At other places in this vicinity a great deal of this loose sand is indurated to a soft, friable, light gray sandstone 35
14. Sand, massive, reddish-buff, bearing nodules of lime near base.. 14

From this point to the top the section is described as the southwest corner of Coördinate H-5.

13. Sandstone, medium-grained, friable, buff-colored, weathering into a cliff with rough surface. At this point it appears to contain a little clay and is therefore not the typically friable sand which weathers into caverns and pinnacles. This is the No. 3 bed ..... (about) 5
12. Sand, massive, slightly resistant. In places this is buff-colored while in others it is white. Contains considerable secondary

Thickness in feet

lime as stringers. Where this bed is white it is found to contain a great deal of lime which is usually soft and powdery 4

11. Sand, somewhat similar to Bed 12 above, somewhat stratified, and bearing less lime. There is a little lime between some of the layers. The color is buff. In the lower part this bed contains blocks of sandstone of about 1 foot in thickness and showing fine laminations. In places there is a continuous induration from the base of this bed to the top of Bed 13. This bed differs from Bed 13 in its stratification and induration into blocks and slabs. In some places, however, there is no induration and the bed is represented by loose, massive, soft sand 8

10. Sand, medium fine-grained, soft, massive, dark to light buff in color; granis finer than in Bed 11 above 15

9. Sand. Similar to Bed 10 in being massive and having fine grains, but the color is a reddish-buff to a little darker than Bed 10. Shows faint thin lines of stratification; lime nodules in abundance. Lower 5 feet lighter in color and containing a little more clay. The whole bed appears to bear a little more clay than does Bed 10 22

8. Clay, dark brown; contains little or no grit; a few lime nodules; "manganese" stains 6

7. Sand, medium-grained, and mixed with a little clay; massive, red-buff in color, and somewhat resembling Bed 9 of this section; rather poorly exposed; contains numerous nodules of lime 32

6. Sand, coarse, irregular-grained, in a matrix of brown or red-brown clay; contains an abundance of lime nodules, the percentage being about 50 per cent toward the top. The material is unstratified 5.5

5. Clay, brown mottled with green; contains a little grit and numerous lime concretions; "manganese" stains on the clay 3

4. Grit, brown or dark buff in color, massive; very coarse and irregular grains, some of which are considerably larger than a pin head and even approach the size of BB shot. Contains no clay as matrix but at intervals of about 2 or 3 feet there is a layer of clay no more than an inch thick. The sand has a dry, friable feel as though whatever clay it had contained had been leached out. Five feet from top is a 1-foot ledge of gravel, the pebbles of which become as large as peas. Toward the base the grit appears to become considerably coarser in texture, approaching a fine gravel. In this part there are also thin lenticular layers of indurated sand. At some localities these layers seem to be more numerous and are seen to dip at high angles, suggesting some stratification or assortment of material. It is believed that this member continues downward

	Thickness in feet
for the unexposed 27 feet below, but the exposures are too poor to show this definitely	33
2. Unexposed. Probably a continuation of Bed 3 of this section	27
1. Clay, brown	5

Section 12. East central part of Coördinate D-2.

9. Caliche, indurated as the uppermost cap of No. 1-A bed. Beds 7, 8, and 9 of this section belong to the No. 1 bed	5
8. Non-resistant caliche	20
7. Caliche as an indurated bed; the No. 1 bed or top cap	10
6. Unexposed; covered by debris of caliche and gravel	33
5. Sandstone, friable, gray to buff in color, laminated, and cross-bedded. Weathers into rough layers and caverns; contains large pieces of gravel and small white clay inclusions. At this point there is little difference between this bed and Bed 1 of this section. Locality 15. Bones were found scattered from here down to Bed 1 and a few good teeth were obtained; the No. 2 bed	10–25
4. Clay, sandy, considerably more clayey than the bed below, gray-brown, fine-grained. There appear to be a few indurated sand layers near top	23
3. Similar to Bed 2 of this section, but contains partings of gravel and clay balls and interbeds of brown clay; lime nodules and aggregations in this bed	27
2. Sand, medium fine-grained, loose, buff-colored. Base not well exposed; appears to bear gravel near base	17
1. Sandstone, gray, friable, composed of medium grains and containing a little gravel and inclusions of white clay in varying sizes. Weathers into stratified layers and shows fine laminations; pockets of gravel and clay balls at base. The No. 3 bed	6

Section 13. South central part of Coördinate N-4. South of Mendota and west of the Mendota scarp road.

12. Sand, very fine-grained, with caliche as nodules, pipes, and irregular beds; buff color; no prominent ledges but rounded hills at top of plains	4.5
11. Sand, very fine-grained, limy, friable, buff in color	3
10. Clay, brown, limy	4
9. Caliche, sandy. Locality 19	8
8. Sand, fine-grained, buff in color. The lower part contains a few nodules and stringers of secondary lime while the upper part is highly impregnated; bed not well exposed	11
7. Sand, fine-grained, limy, light gray or light buff in color; in places almost white. This is parted from Bed 8 above by a	

Thickness in feet

thin, irregular layer of caliche. At the base is a nodular caliche bed about 1 foot thick, which is probably an impregnation of the bed 10

6. Sand, similar to that above it, but containing lenses and partings of clay; brown in color. The base is more clayey and terminates in a thin clay bed 16
5. Sand, firm, limy, light gray-brown or pinkish or even white in color; grains a little coarser than upper material 2
4. Clay, sandy, very fine-grained, light buff to light greenish in color; weathers easily 3.5
3. Sand, firm, as in Bed 5 of this section. Beds 3, 4, and 5 of this section are seen in places to be one bed 4
2. Sandy clay and clay, gray-brown in color, very fine; poorly exposed, but thickness is probably correct 45
1. Sand, massive, red-brown in color; contains lime nodules. This bed probably extends down to the No. 3 key bed, which is some 30 to 35 feet below this member 20

Section 14. Southwestern part of Coördinate O-4.

5. At base is a limy, silty clay of about 2 feet in thickness, overlain by a faintly-bedded, friable, sandstone containing lime. This is a fine medium-grained sand, gray to buff in color. There are a few partings of sandy clay. Induration here not well developed, but this is the No. 1-A key bed which is well exposed farther to the east ..... (exposed) 10
4. Sand, fine-grained, limy, reddish in color, although near its base it is quite white from lime content; massive; 5 feet from base is a layer 1 or 2 feet thick containing some fine-grained sand. At places this indurates. From here to base there is a sandy clay with streaks of lime and this is usually cross-bedded and bedded in wave-like folds. Where exposures are good this may be classed as a separate bed, but usually it cannot be seen 22
3. Sand, fine-grained, calcareous, white to light gray in color, firm although not indurated; forms conspicuous bed. Occasionally one bed but usually parted by clayey layer. There are in places small balls of clay and a few large sand grains. Laminated, usually horizontally. The No. 1 key bed 8–10
2. Clay, brown, interstratified with silty clay, the beds being about 2 feet thick; weathers like clay 34
1. Sand, massive, red-buff in color, loose, very fine-grained; does not contain usual lime nodules 25

Section continued at mesa to west.

6. Sand, fine-grained, red-buff in color, indurated in distinct layers, friable, more or less limy. This may turn to caliche ... 20

	Thickness in feet
5.	11
4. A lens of clay comes in	16
Thickness from Bed 2 of Section 14 to the top of the No. 1 key bed	38

Section 15. Central part of Coördinate P-2.

5. Sandstone, fine-grained, massive but irregular in induration, soft in places; more of a mixture of fine brown sand, clay, clay balls, and caliche impregnations; light buff in color. In most places this bed forms a bluff with the No. 1-A bed. There is no distinct bed, but it extends above the No. 1-A bed for 12 feet or more, with an occasional ledge of the above as well as caliche	12
4. Sandstone, medium-grained, friable, the grains irregular in size; a little lamination seen, but poor stratification; not well indurated but stands out as a ledge; some clay inclusions. The No. 1-A bed	8
3. Sand, medium to coarse-grained, loose, light-colored, possibly bearing a little gravel; some clay balls present, especially near top	16
2. The No. 1 bed as seen at Section 14	10
1. Sandy clay or interbedded sand and clay, brown in color. Top exposed	

Section 16. Central portion of Coördinate P-2.

6. Similar to Bed 5 of Section 15. About 40 feet of this and other similar materials	
5. The No. 1-A bed. Sandstone, laminated, friable, containing clay balls and minute clay pebbles and interbeds of clay material	10
4. Sand, loose, light buff in color. Midway is a 1.5 foot layer of sandstone. Above this is a zone of large clay balls. The base of the No. 1-A is irregular and at this point the interval is small. The same is laminated and contains small clay balls	5
3. The No. 1 bed	10
2. Clay, brown; upper part silty	34
1. Sand, massive, red-buff in color. Top exposed	

Section 17. West central part of Coördinate O-4.

6. Sand, limy, buff-colored, fine-grained, with considerable caliche	10 plus
5. The No. 1-A bed. Induration not continuous. At base there are 2 feet of clay balls in sandy clay. The sand is friable, medium-grained, limy, and contains pebbles. Laminated and cross-bedded	10

		Thickness in feet
4.	Clay, silty, brown. In upper portion, limy and exposed in a bluff, and this portion is a light gray limy sand	16
3.	The No. 1 bed, which may be subdivided as follows:	
	c. Similar to "a." Limy layer at base. Both "a" and "c" are limy	12
	b. White clay, limy, possibly containing a little ash	1.5
	a. Pinkish-gray firm sand, laminated unevenly; grains medium fine; some very small clay pebbles; a light gray clay at base	5
2.	c. Brown clay as in "a" of this member	15
	b. Brown silty clay with thin plates of indurated silt	6
	a. Brown clay grading up to the next subdivision	8
1.	Sand, red-buff in color, massive, with lime nodules. The usual exposure	25

Section 18. West central part of Coördinate M-4.

3.	Sandstone, gray-buff in color; faintly-bedded, medium-grained, friable, limy; exposed as a resistant bed; contains white clay pebbles and a few nodules of lime. There is loose gravel on the slope of this section and it probably comes from Bed 2 as well as from Bed 3 of this section. This bed is No. 3 or lower key bed	8
2.	Sandstone, laminated and bedded, friable, medium-grained, gray-buff in color; contains lime nodules and white clay inclusions. This part does not stand out as a resistant bed	11
1.	Sand, buff-colored, massive, fine-grained; contains lime nodules; a little clay in parts; poor exposure	40

Section 19. Central part of the east line of Coördinate N-3.

4.	Sand, indurated. This is the No. 3 or lower key bed. Buff in color, medium-grained; at base of bed a 1-foot bed of clay balls and gravel as well as a little gravel in the sandstone	17
3.	Clay, brown, limy near top	2.5
2.	Sand, coarse-grained, loose, brown, possibly containing some gravel	12
1.	Sand, massive, red-buff in color; lime nodules abundant; only top of this bed exposed	18

Section 20. Northwest part of Coördinate M-5.

6.	Caliche. Here called the "lower cap," but is in reality the No. 1 bed	10
5.	Poorly exposed material which looks like clay interbedded with sandy clay. A few streaks of secondary lime near top	45
4.	Sandstone, friable. Is indurated only at this point. The No. 2 or "intermediate" bed	8

Thickness in feet

3. Clay, brown; possibly some interbeds of sandy clay; some platy layers of indurated silt noted 27
2. Sand, massive, red-buff in color; lime nodules; the usual exposure 45
1. Sandstone, gray, limy, friable, composed of medium grains, faintly-bedded; induration thicker than usual. The No. 3 or lower key bed 15

Section 21. Northeast part of Coördinate M-6. In old road just north of Triangulation Station "D." Poorly exposed.

7. Predominantly caliche with a hard cap; poorly exposed 15
6. Sandstone, cross-bedded, laminated; prominent ledge 6
5. Caliche; similar to Bed 4 of this section but more highly impregnated with lime 5
4. Sand, buff-colored, massive, very fine-grained, impregnated with lime; nearly all caliche at this point; capped by a 1-foot limy clay layer 9
3. Sandstone and soft sand, cross-bedded, medium-grained, friable, very limy; a great number of small angular and rounded pieces of lime contained as gravel 6
2. Clay, brown, with a few silty streaks 19
1. Sand, red-buff, massive. The usual exposure. Top exposed 2

Section 22. Central part of east half of Coördinate M-6. This section is exposed in a vertical bluff and therefore slight variations in texture are prominent. The top of the No. 2 or "intermediate" bed is indistinct because it is not indurated, but it is thought to begin in the lower portion of Bed 8 of this section.

9. Sand, medium-grained, laminated. Thought to be the No. 2 bed 15
8. Sand, silty, fine-grained, buff-colored, with few limy plates; weathers to clay; poorly bedded 21
7. Similar to Bed 3 of this section 3
6. Similar to Bed 2 of this section but indurated at base 4
5. Similar to Bed 3 of this section 3
4. Similar to Bed 2 of this section 3
3. Clay, massive, impregnated with lime, brown, weathers like clay 2
2. Sand, fine-grained, buff-colored, very slightly resistant 2
1. A caliche cap which is equivalent to the No. 1 bed. The lower 15 feet are clayey with lime nodules and are considerably softer than upper portion 30

Section 23. Southwest corner of Coördinate M-10.

6. Caliche, grading down to sandy caliche at its base. The highest cap as exposed in this immediate area 15

		Thickness in feet
5.	Clay, brown, impregnated with lime	4
4.	Sandstone, laminated, medium-grained, somewhat limy, and buff in color; forms prominent ledge; probably No. 2 bed	6
3.	Sand, chiefly, loose, medium-grained, brown in color. The upper 10 feet clayey. This material is extremely conglomeratic and cross-bedded. The conglomerate is composed of gravel and reworked pebbles of caliche varying in size and not well rounded. There are thick beds of this latter material occurring in lenses and highly cross-bedded. There are also numerous red-brown clay balls and clay lenses, and the clay in the upper part of this bed is purple in color. In places a thick conglomerate at base. Locality 22. A few horse teeth, a vertebra, and one or two other bones have been collected	36
2.	Clay, sandy; the lower 5 feet darker buff in color and more clayey and grades down into the next member	13
1.	Sand, red-buff, massive with numerous lime nodules; usual bed overlying the No. 3 bed (exposed)	20

Section 24. West side of Coördinate P-3.

7.	Sand and sandy clay mantle, brown, bearing some secondary lime nodules	0–25
6.	Probably same as Bed 5 of this section but contains more lime	3
5.	Volcanic ash which appears to be a little finer in texture than Bed 4 of this section; thinly laminated in lower portion, becoming more thickly bedded higher; ripple marks present; cream to white in color	7
4.	Volcanic ash, very coarse, white in color; soft and may be powdered between fingers; faintly laminated; porous in its upper portion; rests directly upon the clay bed. This differs from the overlying bed in being coarser and having numerous pores. It is of excellent quality and free from lime	0.5
3.	Clay, light gray-green or cream-colored, hard, slakes readily when wet. Contains some grit near base, but less farther up, although whole is sandy and may contain a little volcanic ash besides the sand grains. When there is a very fresh exposure this clay grades imperceptibly up from Bed 2 of this section and appears to be the same. An older exposure shows Bed 2 of this section to be massive while this member is fractured in irregular joints. Neither of these beds shows any stratification. The contact of Bed 3 and the overlying volcanic ash is laminated in layers from ½ to 2 inches thick, but farther up weathering has brought about massive beds 3 and 4 feet thick	1.5–20

	Thickness in feet
2. Sand, light gray-green or cream-colored, fine-grained, with clay matrix; can be picked into easily; in places contains numerous vertebrate fossils; massive. Locality 20	3.5
1. Sand, red, with clay as matrix; capped by a hard 6-inch bed of red sand with lime nodules (exposed)	2

Section 25. East line of Coördinate K-11.

Here is an exposure of Red Beds in contact with basal Lower Pliocene. At the water level there is a bed which consists of a very fine-grained sand indurated with gypsum, only about 1 foot of which is exposed. Above this there are about 2 feet of loose, unstratified, soft, red-brown, medium-grained sand. This is also probably Red Beds. Immediately above this there are about 2 feet of conglomerate made up mostly of reworked Red Beds material. The fragments are both angular and rounded clay balls. Boulders consist of sandstone and rounded nodules of powdery lime. This is the basal conglomerate of the Lower Pliocene. Overlying the conglomerate there are 15 feet of interbedded and coarse-grained, laminated and cross-bedded, friable, gray and brown sandstone, interbedded with gray and brown clay, some of which is pure and unctuous.

Section 26. Southeast corner of Coördinate K-13.

In the southwest part of Land Section 128, H. & T. C. R.R. Company, Block 1, on the south side of the Canadian River, there is an exposure which may be described as follows: Near the upstream portion there is a 100-foot section; at the base there is a 3-foot bed of highly crumpled gypsum, overlain by beds of sandy clay, medium-grained sands, and very fine-grained sands with a few indurated layers, all of which display the characteristic Red Beds appearance. The beds dip south and west at very high angles and there is a little faulting present, all of which is due to pre-Pliocene slumping.

Section 27. South central portion of Coördinate K-14.

On the north side of the Canadian River, opposite Section 26, is a section described as follows: The Red Beds offer a more or less continuous exposure for about a mile along the river in bluffs from 50 to 75 feet in height. There is gypsum near the base together with clays and fine-grained sands which are occasionally indurated and in all respects similar to Section 26 on the opposite side of the river. The Red Beds dip at high angles toward the west, south, and east with no apparent uniformity. The top of the Red Beds has been planed

Thickness in feet

off virtually level, and upon this angular unconformity the Lower Pliocene has been deposited.

The basal Lower Pliocene is composed of gray to buff sandstone with a great many red sand grains. The sandstone is indurated to a semi-quartzite in some places, while in others it is soft and friable. The sandstone at the base contains much gravel, of sizes varying from small pebbles to rocks weighing as much as ten pounds. These lower beds contain balls of clay and other fragmentary material derived from the Red Beds. These beds are interbedded also with gray clay. There is an average thickness of 15 feet. A few vertebrate fossils were collected (Locality 25) and determined as Lower Pliocene.

Section 28. Southwest corner of Coördinate C-18, northeast corner of county.

3. Caliche. Soft at base but soon hardening; usually only basal 10 to 20 feet indurated, but in places as much as 30 feet; exposed 30
2. Sand, loose, buff or brown-colored, massive; fairly coarse-grained. (Sample No. 1 of Mechanical Measurements.) This grades up to Bed 3 18
1. Sand, massive, buff-colored, highly impregnated with lime nodules, fine-grained 20

Section 29. Central part of east line of Coördinate J-13.

5. Sand, massive, coarse, brown; overlain by soil 3
4. Clay, unctuous, dark red-brown, mottled with gray ..... (about) 3
3. Sand, light gray, clayey, shows no bedding. This material shows innumerable fresh water and land shells and is the same bed as seen in the valley of Red Deer Creek in the southwestern part of the county. Much lime is present, stringers of caliche showing where the member is exposed. In places this bed is parted by a 2-foot layer of brown laminated sand 6
2. Sand, principally. The lower portion is purplish-brown, laminated, coarse-grained, soft sand mixed with a little clay, while the upper portion is a buff, fine-grained sand, laminated and parted by thin layers of purplish-brown clay 15
1. Sand and gravel. Sand, medium-grained, loose, highly top-set and fore-set, with gravel on the bedding surfaces as well as in thin lenses. A few balls of red-brown clay and rounded boulders of grit or arkosic sandstone. The upper part of this member not well exposed 20–35
This member exposed in the bottom of the canyon.

IDENTIFICATIONS OF FAUNAS AND DESCRIPTION OF FOSSIL LOCALITIES

In the following pages are descriptions of the various fossil localities from which material has been collected, together with the identifications of the locality faunas supplied by Dr. W. D. Matthew of the University of California Museum of Paleontology. A reference to the columnar section (Figure 2) will give the stratigraphic horizons of the faunal localities.

All of the available material was collected from most localities, such material weathering out of the sides of the mesas and canyon walls. There were but three localities of sufficient promise for fossil quarries and these were first opened by the authors to learn their extent, and later thoroughly prospected by parties sent for the purpose by the University of California. After the excavations were completed, the writers understand that additional material from Locality 20 was obtained by Dr. Harold J. Cook for the Denver Museum. The localities extensive enough to warrant quarrying were Localities 20, 24-A, and 24-B. It is believed by the authors that these three localities are not yet exhausted. Unfortunately, however, Locality 20 is situated so near the much traveled public highway that it has suffered considerable destruction by curious persons and specimen seekers who are untrained and unskilled in removing the material.

All of the vertebrate material collected by the authors has been sent to the University of California for identification. The invertebrate material from Locality 26 has been identified by Dr. Junius Henderson of the University of Colorado.

Locality 1. Situated in the eastern part of Hemphill County, about 5 miles west of the Oklahoma boundary and about 1½ miles northeast of the town of Gem. It is on the northern break of a high south-sloping hill, where an overlying knoll furnishes the exposure containing the bones. On top of the hill is the U. S. Coast and Geodetic Survey triangulation bench mark "GEM." From the appearance of the deposit the fossils weather from a limited area some 10 feet in extent. More material may be obtained by digging, but the deposit is of small importance. No generically identifiable fossils were obtained at this locality.

Locality 2. Situated in the central western portion of the county approximately 3½ miles west of the city of Canadian, between Red Deer Creek and the Canadian River near the point where they join. The locality is in the southwest quarter of the eastern half of the W. W. Langham land survey.

The stratigraphic position of this locality is immediately below the No. 3 bed. The deposit is poor and there is small chance of obtaining more material. From this place the following material was identified:

Canidae—fragments of skeleton
Mylagaulus cf. *monodon*

Locality 3. Situated about a quarter of a mile northwest of Localities 2 and 4, and on the east and south sides of the isolated mesa which stands out as the last one to the east. It is in the western portion of the eastern half of the W. W. Langham land survey. This locality, like Localities 2 and 4, is immediately below the No. 3 bed. The majority of the following material came from the wall of a box canyon on the south side of the mesa:

Canidae—fragments of skeleton
Hipparion—cheek teeth
Rhinocerotidae—distal end of humerus
Mastodontinae—cheek teeth

Locality 5. Situated in the northwestern part of Land Section 11, Roberts County, about a mile west of the Hemphill County line, and in the first bluff on the north side of Red Deer Creek west of the county line. The locality also extends up a canyon in back of the bluff. The collecting here is poor and only the material that weathers out may be obtained. The horizon is that directly beneath the No. 3 bed. The material which was collected and identified is:

Carnivora—olecranon
Pliohippus—cheek teeth
Teleoceras—M^3, atlas, and scapula
Camelidae—distal end humerus, lunar
cf. *Testudo*—skeleton and broken carapace

Locality 6. Situated in the southeast corner of Land Section 32, Roberts County, about ½ mile west of the Hemphill County line, north of Red Deer Creek and about 3 miles southwest of Mendota. The fossils are found in a recently washed hillside, the drainage from which flows into Hurley Creek to the north. A great quantity of material was found to have washed out from a thin sand bed which forms a parting to a thick clay series. The collecting consisted of gathering the weathered material, as quarrying was not practicable. The identified material is as follows:

Carnivora—metatarsal
Pliohippus—cheek teeth
Rhinocerotidae—tooth
cf. *Prosthennops*—cheek teeth
Ruminant—astragalus
Mylagaulus cf. *monodon*—P_4

Locality 9. Situated in the western part of the county on the northwest side of Red Deer Creek, approximately 3 miles north of Mendota and in the

southeast corner of the Lout land survey near its east line. The fossils at this locality are scarce, and those discovered had weathered from low sand and gravel hills off the main escarpment. The material is from about 40 feet below the No. 3 bed. The following have been obtained and identified:

cf. *Pliohippus*—fragmentary teeth
Proboscidea—fragments of tooth

Locality 10. Situated on the north line, near the northwest corner of Land Section 193, Block "C," and between Red Deer Creek and the Canadian River, approximately 6 miles west and south of the city of Canadian. The locality includes several canyons in the vicinity. The fossiliferous horizon is from 10 to 20 feet below the base of the No. 3 bed, and from this zone a great deal of material has weathered out. In this vicinity there are deep canyons which are not traversable by automobile except by one dim road. The locality does not warrant quarrying. The specimens identified are:

Machaerodus—parts of jaws, limb and foot-bones
Camelidae—navicular
Mastodontinae—fragment of tooth

Locality 11. Situated in the northeast corner of Land Section 194, Block "C," and more or less a continuation of Locality 10. The collecting area is on the east side of a valley and extends for about a quarter of a mile in a north-south direction. In the northern portion the specimens occur in a clay bed usually encased by hard lime concretions, while in the southern part the fossils are in sand. At no place is collecting good, and only the weathered material is available. The horizon is about 20 feet below the base of the No. 3 bed. The fossils found are:

Pliohippus—lower cheek teeth, astragalus
Hipparion—lower cheek teeth, astragalus, phalanx
Camelidae—carpus, cheek tooth, scaphoid, etc.
Rhinocerotidae—metapodial
Mastodontinae—tooth fragments

Locality 12. Situated in the eastern portion of the western half of the W. W. Langham land survey between the Canadian River and Red Deer Creek. There are no roads approaching this locality. The horizon is immediately below the No. 2 bed. Only one specimen was found:

Mastodontinae—tooth fragments, radius, proximal end

Locality 13. Situated in the northwest corner of the Heimbolt tract of land on the northwest side of Red Deer Creek about 1¼ miles southwest of the city of Canadian. It is a small exposure of coarse-grained sandstone beside the road. Its position in the stratigraphic column is low and only about 40 feet above the base of the Cenozoic. The specimen found is:

Hipparion—lower tooth

Locality 14. Situated about ½ mile north of Locality 13 in the Sam Isaacs tract of land just west of the southwest corner of Land Section 78. The fossils which were identified are as follows:

Carnivora—toe bones
Equidae—astragalus
cf. *Testudo*—fragment carapace

Locality 15. Situated in the northwest corner of the county in the south-central portion of Land Section 132, Block 42. The fossil material weathers out from the loose sands and does not warrant further collecting. The fossil determinations are:

Pliohippus—fragments cheek teeth
Hipparion cf. *occidentale*—upper and lower cheek teeth
Hipparion cf. *lenticulare*—upper and lower cheek teeth
Rhinocerotidae—cuneiform
Camelidae—astragalus, tibia
Mastodontinae—fragments of teeth

Locality 16. Situated in the northwest corner of the county near the county line in the northwest corner of Land Section 26, Block 43. The few fossils found had weathered from loose sands and gravels. The horizon is within or a little below the No. 3 bed. The material was identified as:

Hipparion cf. *lenticulare*—upper cheek teeth
Camelidae—astragalus, radius
Merycodus sp. nov.—left lower jaw

Locality 17. Situated in the south central part of Land Section 119, Block 42. A large bluff of loose sand along the creek from a windmill furnished a few fragments and a section of vertebra, the latter being identified as:

Camelidae—cervical vertebra

Locality 18. Situated in Roberts County about ¼ mile west of the Hemphill County line, in the eastern portion of Land Section 32, just northwest of Locality 6, northwest of Red Deer Creek, and west of Mendota. The horizon of this locality is immediately below the No. 1 bed. The material identified is:

Teleoceras—cheek tooth

Locality 19. Situated in the northwest corner of Land Section 16, Block 1, in the western portion of the county, on the slope of a mesa fronting Red Deer Creek valley. An old road, now unused, goes down the escarpment toward the crossing at Mendota. This road is about ½ mile west of the present traveled road. The mesa bearing the fossils is the last one on the west side of this road going north. The fossils are found on the sandy slopes of this mesa as well as in the caliche cap. The best specimens were found in the caliche. The horizon of this material is from 20 to 50 feet above the No. 1 bed. The material identified from this locality is:

Canidae—fragment of lower jaw
Pliohippus interpolatus—palate, lower jaws, isolated teeth
Hipparion cf. *eurystyle*—cheek teeth
Hipparion cf. *lenticulare*—cheek teeth
Rhinocerotidae—tooth fragments
Camelidae—astragalus, cuneiform, scaphoid, cheek teeth

Locality 20. Situated in the western part of Hemphill County about 1 mile east of the county line, in the northeast corner of Land Section 59, Block A-2, about 500 feet north of the Amarillo Canadian highway, 1½ miles by road from the county line, and 20.3 miles by road from the city of Canadian, on the land of C. C. Coffee. The horizon is at the base of the No. 1 bed. The following material from this quarry has been identified:

Carnivora
Canidae
Borophagus cyonoides (Martin)
Leptocyon, sp.
Hyaenarctos, sp.
Mustelidae
Sthenictis, sp.
Felidae
Pseudaelurus ?
Machaerodus catocopis Cope
Perissodactyla
Equidae
Pliohippus interpolatus Cope
Protohippus ansae sp. nov.
Hipparion eurystyle Cope
Hipparion lenticulare Cope
Rhinocerotidae
Aphelops? mutilus Matthew
Artiodactyla
Dicotylidae
Prosthennops cf. *crassigenis* Gidley
Camelidae
cf. *Miolabis*
Paracamelus ærenicola nom. nov. (*Megatylopus gigas* M. & C.)
Paracamelus sp.
cf. *Alticamelus*
Cervidae
Dyseomeryx
Antilocapridae
Dorcameryx optimae gen. et sp. nov.
Proboscidea
Mastodontinae, cf. *Rhyncotherium*

Rodentia
Mylagaulidae
Mylagaulus cf. *monodon* Cope

Locality 21. Situated in the northwest corner of Land Section 49, Block 1. The horizon is approximately 45 feet below the No. 3 bed, where it forms a low escarpment facing Red Deer Creek. Only one specimen was obtained from this locality:

Hipparion—lower tooth

Locality 22. Situated in the middle of the east line of Land Section 52, Block 41, ½ mile north of the Canadian-Gem highway. The specimens weather out of a loose sand and are found in the walls of a deep canyon which may be seen from the highway. The horizon of this material is about halfway between the No. 2 and No. 3 beds. The following was identified:

Hipparion eurystyle Cope—upper molar

Locality 24. Situated in the southeast corner of Lipscomb County ¼ mile west of the east line and 3 miles north of the south line. The locality is on the west side of a flowing creek which parallels the east line of the county. The land is owned by Sibet and tenanted by Bailey, whose house is about ½ mile south of the locality. This locality has subsequently been designated as Locality 24-A, and less than a mile south of it is found Locality 24-B, which is situated in Lipscomb County, 2 miles north of the south line of the county and approximately 1 mile west of the east line. These localities were brought to the attention of the authors through the courtesy of Mr. Rudolph Goettsche of Higgins, Texas. Both of these places have been quarried and yielded:

Locality 24-A: Canidae (small species)
cf. *Aelurodon*
Machaerodus
Pliohippus
Hipparion
Aphelops sp.
Teleoceras ?
Camelidae
Mastodontinae

Locality 24-B: cf. *Aelurodon*
Machaerodus
Pliohippus
Hipparion
Aphelops
Teleoceras
Camelidae
Antilocapridae
Mastodontinae

Locality 25. Situated in the northeastern part of Land Section 128, Block 41, on the north side of the Canadian River, in the eastern part of the county and about 1½ miles down the river from the Conatser Ranch. This collection represents the very basal portion of the Lower Pliocene in this county at the place where it overlies the Permian. The material is extremely fragmentary and scarce, but the following fossils were collected and identified:

Pliohippus—fragmentary lower tooth
Hipparion cf. *lenticulare*—fragmentary lower teeth
Camelidae—metapodial

Locality 26. Situated north of the Canadian River bridge and approximately 2 miles north of the city of Canadian. The road passes near some old highway clay pits. The fossils were found in the pit on the west side of the road, where both vertebrates and invertebrates are in the "gray clay" of the upper part of the No. 2 terrace.

The vertebrate material collected is:

cf. *Equus*—fragmentary teeth
The invertebrates were identified as:
Pisidium
Physa
Planorbis similaris Frank C. Baker

Locality 27. Situated in the southeast corner of Land Section 161, approximately ½ mile northeast of the Conatser Ranch, north of the Canadian River, in the eastern part of the county. The locality is in the same horizon as Locality 26. Just north of the isolated white knob are exposures in the terrace where the following were collected:

Stegomastodon—lower jaw
Mylodon—tibia

Locality 28. Situated in the northeast corner of Land Section 161, Block 41, north of the Canadian River and about 1½ miles northeast of the Conatser Ranch. There is a deep canyon cutting back into the terrace and on the southeast side of this canyon at a fence are found numerous specimens of the following bones:

Procyon—M_1
Geomys—lower jaw
Cynomys—upper teeth
Leporidae—teeth, limb bones
Nettion—humerus

AGE DETERMINATIONS FROM THE FAUNA

Dr. W. D. Mathew, in a manuscript entitled "Observations on the Tertiary of the Staked Plains of Texas," and in his correspondence relative to the Hemphill County collections, has given a good idea

of the age of the Hemphill County Lower Pliocene beds and their correlation with other areas. The work of Cummins and Cope, 1890–1892; J. W. Gidley, 1899–1901; Lull, 1911; and Matthew, 1924, has divided the Panhandle Pliocene and Pleistocene into the Clarendon, Blanco, and Tule (Rock Creek) beds, which Matthew groups under the term Panhandle.

Gidley regarded the fauna of the "Goodnight beds" of Cummins as identical with the Clarendon fauna. Matthew regards the Clarendon fauna as "undoubtedly Lower Pliocene, probably equivalent to the later phase represented by the Republican River and Upper Snake Creek faunas, and later than the Valentine fauna of Nebraska." He believes the Blanco to be clearly later than the lower part of the Panhandle. Matthew states that the expedition of 1924 "failed entirely to find any indication of an unconformity or break at Mulberry Canyon, or any evidence of a separate fossil fauna intermediate between Clarendon and Blanco in age." According to this observation, the Tule "is later than all of the Panhandle succession, except perhaps a few feet at the top."

In his correspondence, Dr. Matthew states rather clearly the relationship of the Hemphill County Pliocene beds and the need for the new name "Hemphill", which this paper introduces, to be applied to them as a faunal horizon name. He gives the following reasons to warrant this addition to the nomenclature:[2]

1. My first reaction was to call these beds a northeastern extension of the Clarendon. Further study of the fauna showed, however, that it is decidedly later than the Clarendon, and about halfway between it and the Blanco; although I think both fall within the Lower Pliocene if the Blanco be regarded as Middle Pliocene.

2. Comparison of the Equidae with Cope's types from the "Goodnight beds" show identity of fauna as far as can be judged from the very scanty material that Cope described from that "formation." I should not hesitate to call the Hemphill County Pliocene a northeastern extension of the Goodnight beds, except that

3. Gidley declared in 1903 as a result of his three summers' field work that the Goodnight beds did not exist as a formation distinct from the Clarendon. I can reconcile this with the fact that the fauna is distinct (although he did not think it so) only by supposing that the little channel-gravel bed from which it was secured was a local lens of later age than the Clarendon but not connected so far as known with any considerable "formation." I can hardly revive Goodnight as a formation name without evidence that Gidley was wrong

[2]Letter of Dr. W. D. Matthew to Mr. Charles Laurence Baker, December 17, 1929.

in discarding it, although I am using it as a faunal name for the Hemphill mammals, as I have evidence that he was wrong in regarding the faunas as a synonym of the Clarendon fauna.

4. The name Panhandle was applied by Gidley to the main body of banded "clays" that underlie the Staked Plains. He considered the Clarendon, Blanco, and Rock Creek as occupying stream valleys eroded in this older formation, which he though of as "at least partially lacustrine." This, of course, reflected the older view. My re-examination of the beds in 1924 showed that the Clarendon is, at least partially, interdigitated with the lower part of the Panhandle, the Blanco is interdigitated with the upper middle part, and the Rock Creek is interdigitated with the upper part. Unfortunately, I did not locate exactly the type locality of the Goodnight beds. I concluded that the Panhandle covers all the way from the beginning of the Pliocene to recent, as a continuous deposit of eolian (and flood-plain) loess, the fossiliferous beds being stream-valley deposits at different states in its deposition.

TYPES OF SEDIMENTS IN LOWER PLIOCENE BEDS

The Tertiary section, which in Hemphill County is represented only by the Lower Pliocene, is composed of unconsolidated sediments varying in texture from coarse gravel to clays and wind-blown material. On the whole, the lower part of the section is more unconsolidated than the upper. The upper section contains several indurated beds, from 10 to 25 feet in thickness, and the very uppermost part of the section is impregnated with secondary lime which tends to make it resistant to erosion. The color of the material in general is light buff to brown with some thin light gray layers, with the uppermost portion prevailingly white or light gray. The lower portion of the section is coarser than the upper part, as indicated by the fact that 10 feet of gravel form the basal conglomerate and 140 feet from the base there is a 60 to 75-foot bed of coarse arkosic grit. Higher in the section there are beds of gravel, but these are local in extent while the two mentioned in the lower part of the section are persistent. The various outstanding types of sediments in the Lower Pliocene section in Hemphill County are given in the following list and will be discussed separately:

1. Gravels (including lava boulders)
2. Coarse arkosic grits
3. Gray sands and sandstones
4. Buff sands
5. Clays and silty clays
6. Volcanic ash
7. Caliche

Gravels (including lava boulders).—At the base of the Lower Pliocene there are probably varying amounts of gravel forming the basal conglomerate. On the north side of the Canadian River in the eastern part of the county just east of the Conatser Ranch, there is an exposure of about 10 feet showing gravel of various sizes, some of the pieces weighing as much as 10 pounds. As far as can be determined there is no more gravel in the lower part of the section until the horizon of the No. 3 bed is reached. At times the gravel is distributed from immediately below to a few feet above this bed. The No. 3 bed usually contains a small amount of gravel throughout its extent. The gravel above and below this bed is irregularly distributed. It is composed of metamorphic, igneous, and sedimentary materials. The sizes vary from small pebbles to boulders of about 2 or 3 inches in diameter. It has been noted that in this general zone, as well as in some other places, there are vesicular lava boulders, usually well rounded. Some of the pieces are 2 or more feet in length and are "bread crust" bombs, probably transported to a great extent by flotation. The prevailing size, however, is from 3 to 6 inches in diameter. In the horizon between the No. 2 and No. 3 beds there are pockets or channels of gravel similar to those found near the No. 3 bed. Gravel is present also in one or two cases above the No. 1 bed.

Coarse arkosic grits.—The zone of this material is limited to 140 feet from the base and has a thickness of about 60 to 75 feet. It is prevailingly brown in color and near the base is slightly indurated, though on the whole it is massive. Near the top there are thin partings of clay. This material is composed of quartz, feldspar, jasper, magnetite, and phlogopite in decreasing order of abundance.

Gray Sands and Sandstones.—These are found in the upper portion of the section. The gray color is characteristic of the resistant ledges which form the Nos. 3, 2, 1, and 1-A beds, and are confined strictly to their zones. A great deal of lime is contained within these beds and in some places they are altered to caliche. In Section 11 the No. 3 bed is composed of a larger amount of subangular grains of quartz with very little feldspar. In the same section the No. 2 bed is composed very largely of subangular grains with occasional well-rounded, etched quartz grains and some chert and schist grains.

Buff Sands.—These sands have been described at length in the stratigraphy of the section. They lie more or less throughout the section, but are found to be characteristic of the beds immediately above and below the No. 3 bed. Several samples of this type of sediment are described under mechanical measurements. These sands are massive, fine-grained, soft, and usually weather into a more or less perpendicular bluff. They are highly impregnated with small lime nodules.

Clays and Silts.—Clays are scattered throughout the Lower Pliocene from the base to the top. In some of the thinner beds the clay is found to be free of grit, but it is usually in the form of brown clay with a little sand. In the upper part of the section there is a more or less persistent clay series that may be seen on the cross section. In Section "A-B" a well developed clay is present in the zone of the No. 2 bed and to the north, in Section "C-D," this clay has graded into a fine buff sand, showing possibly that the clay and massive buff sand are directly related but represent a slightly different depositional phase. Frequently the clays are laminated by thin, hard, silty plates or silty streaks within the clay. The clays are usually bedded or thinly laminated, although in some places it is difficult to detect bedding planes within some of the exposures.

Volcanic Ash.—So far as can be determined the stratigraphic range of the volcanic ash is not extensive and is confined more or less to the horizon of the No. 1 bed. At Locality 20, in the western part of the county, there is a 7-foot exposure of ash. It is in a pure state except that it contains a little secondary lime. In other places within the No. 1 bed along the west line of the county much chalcedony is noted, and it is believed to have been derived from this volcanic ash.

Caliche.—Caliche is present in the upper portion of the section as a replacement of some of the beds, principally the No. 1 and No. 1-A beds. It is also present, though not so well developed, in the sands and clays above the No. 1-A bed.

SOURCES AND MODES OF DEPOSITION OF THE LOWER PLIOCENE DEPOSITS

In determining the origin of the Lower Pliocene sediments in Hemphill County, it is necessary to consider the headwaters basin of the Canadian River, the major uplifts prior to and during Lower

Pliocene time, and the materials which were eroded during that time. The headwaters of the Candian River in New Mexico extend west and north for about 175 miles into the southwest Rocky Mountains, known in this section as the Sangre de Cristo Range. The principal tributaries are the Mora, Conchos, and Cimarron rivers, which in turn have many important tributaries.

The possible first uplift which is of interest and which has important bearing on the origin of the sediment of the High Plains was the Laramide uplift, which perhaps began in the Benton of Upper Cretaceous and extended into the Lower Eocene. This movement may have exposed to erosion the crystalline cores of the high ranges. A second movement, called here the Santa Fe uplift, took place in the Santa Fe region near the end of Upper Miocene and possibly continued through the Lower Pliocene. This is shown by the fact that the beds near Santa Fe bear a Loup Fork fauna of age near the transition between Miocene and Pliocene and were deposited during or after the Santa Fe uplift. During the time represented by the middle portion of the Lower Pliocene section of Hemphill County, there was volcanic activity, as is evidenced by volcanic bombs and deposits of volcanic ash in the upper part, and as is suggested by more recent eruptions in the valley of the Canadian. This activity must have been more or less intermittent in the upper Canadian basin during Pliocene and Pleistocene.

An extensive deposit of arkosic material has been described in the lower part of the Lower Pliocene section in Hemphill County, and this bed seems to thicken farther up the valley of the Canadian River. This problem must find its solution in one of the following explanations: First, that the arkosic beds of the Pennsylvanian, and probably Permian, which contains a maximum of about 16,000 feet of arkosic and conglomeratic material [reported by Willis T. Lee on the east flank of the Rockies in southern Colorado] furnished a source for this little altered material. Second, that the material was derived from the crystallines of the Rocky Mountains themselves. Because of the small amount of alteration that has taken place, and its sudden appearance in a fairly large thickness, the deposition of this arkosic material would have had to be rapid.

Over eastern New Mexico there are extensive deposits of Upper Cretaceous with widespread distribution of Dakota sandstone and

later Cretaceous with a small amount of upper Comanchean. In this area the nondescript Cenozoic lies upon these Upper Cretaceous formations, and at least a part of their finer sediments could have been derived from the Cretaceous. In Texas the Dakota may have contributed more to their formation, especially in the upper portion of Lower Pliocene. The Cenozoic of the High Plains from Nebraska into Texas is composed largely of Lower Pliocene beds that have been derived from the Rocky Mountain uplift.

It is probable that the greater portion of the materials in the Hemphill County section came from the mountain ranges, but the area to the southeast of them, which is occupied by Cretaceous, must have contributed to a large extent. In the basal conglomerates in Hemphill County and higher in the section than the No. 3 bed, worn *Gryphaeas* were found associated with the gravels. This in itself would indicate that the upper Comanchean in eastern New Mexico was exposed and contributed to the sediments of the Lower Pliocene throughout the entire section.

It is seen from the geologic map of eastern New Mexico that a large basin has been formed by the removal of both the Upper Cretaceous and the Comanche beds, down to and including the upper part of the Triassic. Since the Comanche contributed to the lowest beds of the Hemphill County section, it is probable that the Triassic was also yielding material to this area at the same time. The present elevation of the Comanche beds near Tucumcari, New Mexico, is 4921 feet, and 250 miles down the Canadian River in Hemphill County the elevation of the basal beds of the Pliocene is 2275 feet. This would give a gradient of about 10 feet to the mile. The gradient of the present river within Hemphill County is about 8 feet to the mile.

The Canadian River has likely maintained its general course in New Mexico from Lower Pliocene time to the present and it is probable that during the Lower Pliocene the direction of the river in Texas was somewhat as it is now. This river is probably the agency which deposited the Lower Pliocene material as seen in Hemphill County. Other streams may have aided in the deposition, but the Canadian, from the evidence brought out above, was the most active. It is understood that in certain portions of the Panhandle Lower Pliocene the beds cannot be traced for more than a mile or so because of the irregularity of deposition. However, in Hemphill

County the deposition was regular over a considerable area, which would indicate that there was a broad, braided flood plain across which the depositing streams meandered. During the deposition the Canadian may have had several channels which covered a considerable area in a manner comparable to the rivers in the southern end of the San Joaquin valley of California with their wide delta distributaries. Such a delta distributary would be in the order of a great desert alluvial fan magnified many times.

Various stages are represented in the Hemphill County beds, which show changes in the nature of the deposition during that period. The great thickness of arkosic grit in the lower part of the section would indicate a stage of rapid deposition with a steep gradient and an abundant supply of material from the headwaters, as well as a semi-arid climate. The lower part of the grit section is massive, and toward the top there are partings of clay to show that deposition was more vigorous in its lower portion. In Roberts County, to the west, an exposure of the material was seen to be thicker than in Hemphill County.

The gray sands and sandstones repeatedly mentioned as forming distinct beds in the upper part of the section, and as being parted by massive buff sands, are believed to represent swift-flowing, sand-choked streams simultaneously braided over a large area. This may have been brought about by some change in the headwaters of the river, such as a new area open to erosion or a change in the amount of water carried by the stream. These gray sands are undoubtedly waterlain, for they are lenticular and cross-bedded, and contain clay pebbles and gravel. In some places these gray sands are deposited unconformably upon the underlying massive buff sands as if on a land surface. Vertebrate fossils are associated with these beds, whereas they are not, ordinarily, with the others. Several stream channels have been noted in exposed sections and these are composed of coarse sands and gravels, gray to brown in color, resembling in many respects the above mentioned gray sands. They are thought to have the same origin.

Evidence of Wind Depositon.—The beds of buff sand in the upper part of the section are massive, lack stratification, and weather in vertical bluffs, as do some of the known loess deposits. The color itself suggests that these beds were formed under conditions different from the gray sands. Mr. Charles Laurence Baker and Dr.

W. D. Matthew, who have studied the plains deposits for a number of years, feel certain that wind was the agent of their formation. At the present time wind is playing a great part in reworking the surface deposits, and it is to be expected that this condition prevailed in the past. It would seem that the fine material which makes up the massive buff sands and sandy clays was brought down and deposited by the streams, then reworked and redeposited by the action of the wind. The finer material would have been blown in or reworked from a considerable distance.

It has been noticed that almost all the exposures of the massive buff sands show a more weathered appearance than the other beds, and this would bear out the above suggestion that, as the streams were bringing down the fine sediments, the wind was reworking and redepositing them more or less uniformly over the surface in such a manner as to make up a uniform bed without stratification or lamination. This would cause the characteristics noted in the exposures. At certain intervals there were changes in the character of the river which caused it to deposit the gray sands. In places these sands show an unconformity at the base and represent a flooding of the land surface, now represented by the massive buff sands.

Lines of levels for the purpose of constructing a structural contour map of the strata were run in the western half of the county on the Nos. 1, 2, and 3 beds. These beds had proved to be the most persistent, easily identifiable, and most regular in the section. This fact in itself is an indication that the depositional conditions under which these horizons were formed were different from those taking place in the remaining or lower part of the strata. It was a matter of considerable surprise that these horizons could be traced over so great an area, as the general opinion of practically all students of the later Cenozoic Panhandle and Staked Plains strata has been to the contrary.

The results of this instrumental work demonstrated in a few places that sink holes had been formed by ground settlement as a consequence of the solution of the salt and gypsum beds in the underlying Permian. These could be readily differentiated on the structural contour map. Of far greater importance, however, are features more prevalent and more irregular, which showed that

the attitude of the beds is not strictly horizontal in any of the area so worked. The explanation which first comes to mind is that these irregularities were caused by structural movements; that is, that they were the effects of deformations occurring after the deposition of the strata. However, it is an almost universal rule that structure caused by deformative forces has more or less regularity in form, in direction, and especially in parallelism. This can, of course, be proved almost any place where deformation has taken place, even in slight amount. These Lower Pliocene beds, however, show no regular structures, while the contour map very closely resembles one made of the surface topography of a low rolling region of smooth and flowing contours which has only a small amount of total differential relief, but in which lines of drainage are well formed and separated from each other by low, broad, and smoothly contoured divides. It is possible to reconstruct a system of drainage lines on the contour map, but such drainage lines differ widely from those developed at the present time.

Since the strata so contoured are the finest and most uniformly textured in the section, contain calcareous concretions quite similar to those in the Quaternary loess, weather in vertical bluffs of the common loess habit, and contain no fossils, the suggestion is here set forth that they are dominantly eolian deposits laid down as a more or less uniform blanket over a topography, the result partly of aqueous deposition and partly aqueous erosion, to substantially the same depths over former stream divides, drainage slopes and drainage channel, very much indeed as does the Quarternary loess in the Mississippi basin. There can be no doubt that a large amount of eolian transportation out of the more arid regions farther west is taking place at the present day as it did in the Quarternary. This is obviously a matter of direct observation of sand and dust storms in eastern New Mexico and western Texas at the present time. If the land surface of Lower Pliocene time was covered with grasses or herbaceous vegetation, a large amount of the material in transit through the air would have been trapped then as it is being trapped now. Furthermore, these surfaces of the open plains on which very slow eolian deposition was taking place would not contain vertebrate or plant fossils for the reason that these were destroyed by decomposition and disintegration, and the edible parts used for

food by other animals. In other words, conditions of burial necessary for the preservation of fossils did not obtain except in stream channels or in lacustrine or palustrine basins.

It would be possible, by the painstaking mechanical analysis of a large number of samples, widely distributed throughout this and similar regions, ultimately to develop criteria by which to differentiate sediments of eolian and fluviatile origin. Many lacustrine sediments would have the same texture as eolian sediments, but lacustrine sediments generally betray their origin by their fine lamination. The sediments we are now discussing are markedly free from such lamination.

It is suggested that we have in the phenomena described above an important assemblage of data which should be tested by further investigation, since it may prove to be distinctive and characteristic of former eolian deposits.

The difference in color between the buff and gray sands is a point to be considered in regard to their origin. In the buff sands and clays the color is due to the character of the sediments and to subsequent weathering. It has been stated that the Comanche beds were exposed in New Mexico at the beginning of the Lower Pliocene deposition in Hemphill County, and, since the sediments between the Comanche and the Triassic have been removed, it is reasonable to assume that both were going through the process of erosion at the same time. Both the Triassic and the Dakota of New Mexico contain reddish sands. Under certain conditions of erosion and stream gradient, material principally from the Triassic beds could have been deposited in Hemphill County during the buff sand and clay intervals, which would have given these beds their color. Long exposure at the surface would tend to discolor them.

The gray sands on the whole are of coarser material than the buff sands, which is a difference such as to indicate a change in the source of material. It has been pointed out that the gray sands were rapidly deposited in swift running waters. Under this condition there would be little chance for oxidation. It has been further noted that the color in the gray sands is to a large extent due to an abundance of secondary lime which in places becomes caliche. The lime cement was caused by a large amount of percolation through these coarser, more porous beds, which were the main zones of

underground water movement. That this was true is shown by the fact that the precipitation of caliche follows the definite zones of these beds instead of extending above or below them.

The uppermost part of the section in Hemphill County is composed of buff sands, with some clays and aggregations of caliche lying above the No. 1-A bed and extending to the top of the plains, a thickness of 50 or more feet. On the whole these sands resemble the massive buff sands lower in the section and probably have somewhat the same origin, although wind action seems to have played a greater part. The very top of the plains is covered by clay which is thought to represent wind deposition and further reworking of the material immediately below it.

The entire Lower Pliocene section in Hemphill County contains lime in more or less abundance. The clays frequently carry soft powdery to hard lime nodules and the massive buff sands are characterized by an abundance of lime nodules. The gray sands, as indicated above, contain lime, which increases in quantity until it becomes caliche. The beds of gray limy sand in this county correspond to the typical "mortar beds" of Kansas. The induration of the resistant beds is caused by cementation of the sand grains by secondary lime.

The caliche in Hemphill County has been formed where the beds have remained near the surface for a considerable period of time. It has been mentioned that the gray sands were water channels and derived their lime content from this water. Where these beds were near the surface, capillary attraction brought the water to the surface, and subsequent evaporation precipitated the lime. This is the accepted explanation for the formation of caliche.

Lower Pliocene Climate.—The present climate of Hemphill County and the area to the west is sub-arid and temperate. The mean annual temperature for the past 20-year period was 57.9°, and the mean annual precipitation over the same period was 23.48 inches. The mean annual maximum temperature over a 12-year period was 71.5°, and the mean annual minimum temperature was 44°; the highest temperature over that period was 108° and the lowest, 12°. The mean annual snowfall over a period of 12 years was 9.6 inches. The above figures are for the city of Canadian, which is situated in the valley of the Canadian River. At Miami, which is

situated in the valley of Red Deer Creek, the mean annual temperature over a period of 26 years was 58.5°, and the mean annual precipitation was 22.43 inches. At Canadian, over a period of 26 years, the prevailing wind has been from the south and southwest. It would appear that the wind prevails from the north during the winter months of November, December, January, February, March, and April, and from the south and southwest during the rest of the year, the strongest winds coming from the south. The precipitation is spasmodic, especially during the summer months.

Vegetation in Hemphill County is sparse and consists principally of grasses, with a few trees in the larger valleys.

There is no reason to believe that the climate during the deposition of the Lower Pliocene beds was very different from that of the present time. The materials constituting these beds are typical of arid to semi-arid deposits, being coarse arkosic grit, the possible wind-blown deposit, and caliche. The absence of fossilized vegetation is another evidence of such a climate. Only one piece of fossilized wood has been noted and this is believed to have come from the No. 2 terrace. There is evidence in the fauna that the country was inhabited by roving animals, as well as by those living among the thick vegetation of the river valleys.

GEOLOGIC HISTORY OF THE AREA

THE BUILDING OF THE HIGH PLAINS

The discussion of the geologic history of Hemphill County begins with the top of the Permian, the oldest formation exposed in the county. There is an unconformity between the red beds and the base of the Lower Pliocene with no intermediate beds exposed. Such a break represents an enormous time interval which extends over the Triassic, Jurassic, Cretaceous, and most of the Cenozoic periods.

To reconstruct this lost period, one must look to the areas adjoining Hemphill County, particularly to the west in New Mexico and to the south along the eastern edge of the Llano Estacado. The western edge of the plains' Cenozoic lies upon the eroded tops of the Cretaceous formation just west of the state boundary in New Mexico. Since these beds in several places are inliers in the plains beds, it is concluded that the mantle of the latter deposits is not

thick in this part. Again, in Texas, about 60 miles to the southwest of the Hemphill County area, the Triassic underlies the plains deposits, and farther south the Comanche overlies the Triassic. W. F. Cummins states that the Cretaceous is not found farther north than the Double Mountain Fork of the Brazos River. The Cretaceous outcrops also at the eastern edge of the plains in Kansas, north of the Hemphill County area and in the Anadarko basin of Oklahoma to the east. It is supposed that the area between the Cretaceous outcrops represents an erosional basin of an ancestral Canadian River, though topographic maps are needed to prove such a condition.

The Triassic was possibly laid down and then removed before the deposition of the Cretaceous, and Cummins shows that there was another great erosional interval after the end of the Cretaceous which removed these latter deposits from the country immediately east of the plains. Part of these were, however, removed in the later Cenozoic.

During the Laramide and later movements, in the eastern Cordillera in Colorado and in northern New Mexico immediately east of the Front Range, the Arapahoe, Denver, and so-called Raton formations of disputed Eocene age formed in a synclinal basin, and the area on the east flank of the syncline was probably domed up and subjected to erosion. The doming was possibly responsible for the removal of the Cretaceous sediments in Hemphill County. Under this condition the Eocene could not be laid down in the latter area, but its deposits might have been carried around it or through it on out to the east and deposited.

If a high area existed in the basin which is outlined by the outcrops of the Cretaceous, and the Cretaceous deposits were standing above all others, or if the basin was the result of an ancestral Canadian River in pre-Pliocene time, the area was contributing sediments instead of receiving them in the period previous to the Lower Pliocene deposition. The explanation of the thickness of the Lower Pliocene deposits in Hemphill County, in addition to the probability of there being, as stated above, a broad basin of downwarp or carved out by pre-Pliocene erosion in which Lower Pliocene beds accumulated, is probable that there was more sediment furnished to this

particular area than to any south of it, because the Cenozoic elsewhere is not as thick as this section in Hemphill County. Opposite the south plains to the west in the Cordillera are the Delaware, Guadalupe, and Sacramento mountains, which do not have as steeply inclined slopes, have more resistant beds on their flanks, and are not so high as the mountains in the region of the Sangre de Cristo range west of the Hemphill County area and in the erosion basin of the Canadian River. The greater thickness of the beds in Hemphill County may be attributed to the greater erosion of relatively non-resistant beds on steeper slopes at the headwaters of the streams which contributed to their formation, and from which came the greater amount of Lower Pliocene deposits.

The Lower Pliocene opened in Hemphill County at the end of a great peneplanation which wiped away the Cretaceous and cut into the top of the red beds, whose surface was inclined at a southeastward angle comparable with the attitude of the present Pliocene beds. The surface, though not entirely level, was apparently nearly level. The depositing stream carried considerable water, at least at flood stages, had a fair to steep gradient farther up stream, and an abundant supply of material from the west, all of which we know because only coarser sediments were deposited and these quite rapidly. After about half of the section had been built up in a relatively short time, the character of the sediments changed, either from a change in the source of the materials, in the climate, in the character of the materials at the source, or because the carrying power of the stream, due either to a decrease in the supply of water or to the decrease in gradient, had been reduced. At any rate, the sediments became finer in texture and it is probable that a longer period of time was required to build them up. During and after deposition of the finer materials, it is believed that the relative proportion of wind deposits increased and that much of the already deposited sediments was reworked by winds. That is, the wind shifted the sediments already laid down, and added more from the other areas on the growing plains. At that time the river was meandering through a broad system of delta distributaries and making deposits simultaneously with the winds. The exact ratio between the amount of wind deposits and the amount of those of fluviatile origin is not known, but wind deposits are probably

abundant. Throughout the latter part of the Lower Pliocene there must have been a considerable amount of volcanic activity in the region farther west as is shown by the deposit of volcanic ash in the beds and of volcanic bombs which appear to have floated down the streams from the basaltic eruptive areas of northern New Mexico. At the end of the Lower Pliocene the plains surface was built up almost to the present general level. Later on occurred a rejuvenation and down-cutting which resulted in the present Canadian River channel.

THE HISTORY OF THE CANADIAN RIVER AND ITS TERRACES IN HEMPHILL COUNTY

The Pleistocene history of the county is contained in the Canadian River and its terraces. Under the heading "Physiography," a detailed description of the Canadian River valley has been given, and only a few brief items will be mentioned here. In the western part of the county the valley of the Canadian is about 10 miles wide and 450 feet deep, while in the eastern portion it is about 18 miles wide and some 375 feet deep. South of the river the valley is much steeper than on the north side, and in the western portion of the county the gradients of the streams coming into the river are steeper than in the eastern part. On the south side of the river there is a relatively small amount of terrace material, which overlies the Lower Pliocene beds, and there is no indication that since Lower Pliocene time the Canadian River ever meandered farther south than its present course. On the north side, however, the course of the river has not been limited, as will be brought out in a later discussion. The gradient of the Canadian has been estimated to be about 8 feet to the mile.

The fill of the river channel is very thick, and within this county, at least, the base has not been reached. In the soundings made by the Santa Fe Railroad preparatory to building its bridge across the river at the town of Canadian, the fill was found to be at least 123 feet deep in the deepest test, and from the log there is no indication that the base was approached, although the Santa Fe considers the base of the scour is not much more than 200 feet. Attention is called to the plot of the soundings as made by the Santa Fe (see Figure 8).

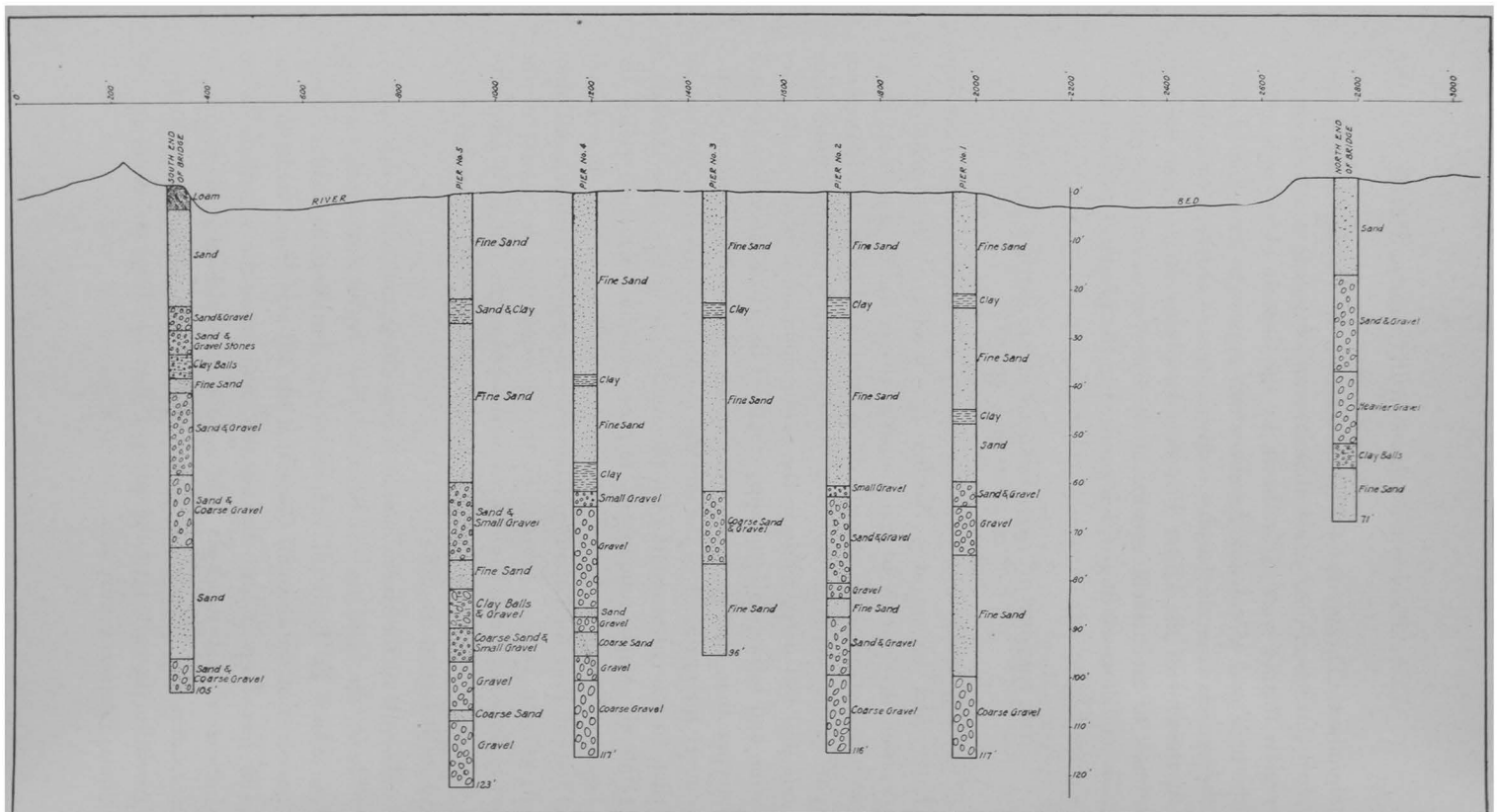

Fig. 8. Cross section showing soundings for Santa Fe Railroad bridge across the Canadian River, Hemphill County, Texas.

The record of the deepest of the soundings, that at Pier No. 5, shows from the top down: (1) 22 feet of fine sand, which constitutes the material now seen in the river bed; (2) 5 feet of sandy clay which to the north and center of the river is logged as clay; (3) 33 feet of fine sand; (4) 16 feet of sand and small gravel; (5) 6 feet of fine sand; (6) 8 feet of clay balls and gravels; (7) 7 feet of coarse sand and small gravel; (8) 10 feet of gravel and sand; (9) 2 feet of coarse sand; and (10) 14 feet of gravel with sand. This makes a total depth of 123 feet. Note: "At 121.5 feet a good flow of water. Pumped thirty minutes without lowering an inch; apparently on large boulder or solid rock. Pipe turned easy. Pressure at this point 110 pounds." The remainder of the soundings are similar to this, although in some there are two beds of clay in the upper portion and varying thicknesses of fine sand near the base.

From the section of the soundings, it is noted that the basal portion contains coarse sands and gravels and clay balls, whereas the upper portion is limited to fine sands with occasional partings of clay; and that in the center of the river the sand is deepest, while on the sides it is shallow, thus giving the lower limit of the sands the concave shape of a valley cross section. The gravel and clay balls on the sides of the river appear at about 20 feet from the surface, while in the center they begin at about 60 feet. This may be interpreted as either the original depositional slope, or as subsequent scouring of the gravel in the center and deposition of fine sand in its place. The latter is more probably the case. At the time of the deposition of the material as represented in the lower portion of the soundings, the gradient and character of the river were quite different from what they are now. From the logs it is not possible to determine the origin of the gravels, etc., but a great amount of this material may have come from the basal Lower Pliocene beds while the Canadian valley was being formed. The gravels in the lower part of the soundings showed to contain water at hydrostatic head from 30 to 114 pounds pressure, and in a number of cases the drilling water was lost, showing that the gravels and sands were in pockets or lenses.

There are three outstanding possibilities to consider in the origin of the gravels in the base of the river. The first is that the gravel belongs *in situ* to the basal bed of the Lower Pliocene; the second, that the gravel was deposited by the river from a western source with additional material from the adjoining Lower Pliocene beds, prior to the deposition of the terraces; and the third alternative, that, after the deposition of the terraces, the river cut its channel

down to bed rock and then deposited the gravel and coarse sand. The last explanation is preferred by the authors.

The presence of the gravels in the lower part of the soundings helps to form a complete history of the Canadian River valley and its terraces. The sequence of events would be somewhat of this order: After the deposition of the Lower Pliocene beds, which extended in this area to the top of the plains, a period of erosion began and the river cut its valley at least 575 feet deep to the top of the Red Beds. Overburdening of the stream deposited the gravels, and this upbuilding continued to the present level, with the materials becoming finer as the present time was approached. The terraces were laid down in stages more or less static followed by slight periods of rejuvenation in the erosional cycle.

There is a possibility that the terraces were deposited after the river cut down to bed rock and before the gravels, which represent a rejuvenation in Hemphill County and erosion in the headwaters of the stream, were deposited. This would necessitate a second period of deposition followed by subsequent erosion to the present level of the stream. If such a period of deposition existed, then it is quite possible that the time interval is equivalent to the Lafayette and can be correlated with the Seymour formation in northwest Texas.

From this description of the Canadian River, it is apparent that it has not occupied channels south of the present one. On the north side of the valley there is a considerable area which it may have occupied during its history after the deposition of the No. 3 Terrace, and probably after, or less probably during, the formation of the No. 2 Terrace. In the eastern part of the county just below the Conatser Ranch, there is a stretch of 2 miles through which the river has cut a channel in the Red Beds, exposing a bluff on either side of a narrow channel. About 5 miles down the river from this point there is a small exposure on the north side of the river and a larger exposure on the south side, which would have limited the course of the river to this channel. It is noted also, at the two points mentioned above, that the terrace on the north side comes relatively close to the present river channel and caps the exposure of the Red Beds. The above limitations confine the river in the eastern portion of the county to its present channel, and there could

have been little or no meandering. The presence of the above described bluffs on either side of the river would indicate that the channel is new, and that the Canadian had other courses in relatively recent time. The northern extent of the terrace on the north side of the river will be seen on the geologic map, and it is noted that this northern end is fairly well defined. The streams flowing south are deflected when they approach this terrace and in all cases their courses are offset before they pass through the terrace. This would suggest that the offset portion follows an old river valley. North of these terraces is a great expanse of sand hills which appear to have been reworked into dunes from underlying loose sands suggestive of terrace or river deposits. For the above reasons it is postulated that a former channel of the Canadian, the one followed immediately before it assumed its relatively recent one in the eastern part of the county, occupied the area north of these terraces, with possible meanderings as far north as a line east of Glazier. This channel could have entered at a point about 1½ miles south of Glazier, and passed out of the county south of the area of undifferentiated Lower Pliocene beds shown on the map. Just east of the state line, the river in Oklahoma turns to the north for a short distance, and if the old river passed out of the county at the above mentioned point, it would meet its present course somewhere about this turn.

Beginning in the western part of Hemphill County there is a tendency, most noticeable in the eastern part of the county, for the river to bend toward the south. From here it enters Oklahoma with a bend to the north, and continues its course in large broad bends or meanders for about 60 miles until it reaches Taloga in Dewey County, and from here it turns southeast following the strike. There are apparently resistant beds in the Woodward formation which have caused the Canadian valley to become sufficiently base-leveled to cause the tendency toward meanders beginning in the western part of Hemphill County, Texas. This influence has probably caused the Canadian to shift its course through the county to the south as outlined in the above discussion. It will be noted that there are a great many more drainage lines entering the valley from the south than from the north, and under normal conditions this would have caused the river to shift northward instead of to the south if there were no greater influencing agencies.

The following suggestion is offered: The narrowing condition in the eastern part of the county, where the river is entrenched within the resistant Red Beds could have been caused by a slight uplift in the course of the consequent stream of the Canadian, which would have occurred immediately after the deposition of the No. 2 Terrace. This possibility would also account for the deflection of the creeks as they approach the northern limit of the terrace. It is noticed that the Canadian River is apparently deflected to the north to a marked degree on the north flank of the Panhandle buried mountain ridge.

At the time of the formation of the No. 3 terrace, which lies in the vicinity of Glazier and has been recognized only in this limited area, the Canadian River may or may not have occupied the approximate channel it had during the deposition of the No. 2 terrace. Several references have been made to the fact that the No. 2 terrace on the north side of the river is better developd than on the south side, which is another indication that the terrace on the south side of the river was farther away from the depositing river than that on the north side of the present channel. It seems most likely that the No. 3 terrace was deposited during the early part of the erosion cycle when only a small amount of the plains material had been eroded, for the base of the No. 3 terrace lies directly upon the top of the indurated No. 2 bed of the Lower Pliocene in the area west of Glazier. In the vicinity of Glazier, both to the north and east of that town, there is a broad flat area covered by sand hills and sand dunes which represents the general surface of this terrace. This plain extends at least to the line of the county on the north, and nearly as far east as the area of undifferentiated Lower Pliocene. South of this plain, and at a lower elevation, is the plain corresponding to the No. 2 terrace. The No. 3 terrace as shown on the map probably represents the northernmost side of the valley at that time, and the terrace may have had a widespread distribution to the south in the area now occupied by the present Canadian River.

Red Deer Creek, the one major tributary to the Canadian River in Hemphill County, has been described under "Physiography." On the west line of the county, about 2 miles west of Mendota in a tributary of Hurley Creek, there is an exposure of dark gray, sandy clay containing numerous fresh water shells, and in all respects

similar to the gray, sandy clay in the upper portion of the No. 2 terrace on the north side of the Canadian River. It is probable that the exposure on Hurley Creek could be correlated with the No. 2 terrace, and that during the deposition of this terrace along the river there were similar phases of it represented in Red Deer Creek, although at a higher elevation. It is likely that if terraces were present along the Red Deer valley they have since been removed by active erosion. It is therefore believed that Red Deer Creek existed and had formed a considerable valley at the time of the deposition of the No. 2 terrace.

STRUCTURE AND SUBSURFACE CORRELATIONS

Structure.—The Lower Pliocene beds are exposed in the greater part of the area south of the Canadian River, and there are small areas where they are exposed in the northwest and northeast corners of the county. The north central part of the county, where the surface is covered with sand, presents practically no information on the attitude of the Lower Pliocene beds. The beds giving the most complete record are those in the escarpments and mesas exposed in the western part of the county. The beds of the Lower Pliocene are virtually horizontal and appear so when viewed in the field. However, when numerous elevations are taken on the beds, it is evident that there is some irregularity to their surfaces. As near as can be determined, the regional dip or slope of these beds within the county is to the east with a south component. The degree of this slope is slight, and, if determined, would not be over 8 feet to the mile.

On the north side of the Canadian River in the eastern part of the county, the base of the Lower Pliocene lies horizontally upon the eroded surface of the Red Beds. It is thought that throughout the county the basal beds conform to this outcrop and parallel the upper horizons seen on the surface. This is substantiated by data from the Hoover, Schaller, and George wells. The Ruby Jones, Jones, Hopkins, and Gageby wells are not so situated that they can be used for this interpretation. A sketch has been prepared which shows the elevations on top of the Red Beds, both from wells and surface outcrops. From this it is seen that the highest point is at the George well in the southwest part of the county, in which the top of the Red Beds has an elevation of 2395 feet. To the north in Roberts County, the Gibson Oil Company's No. 1 Jones has an

elevation of 2340 feet for the top of the Red Beds. The Santa Fe well at Canadian gives an elevation of 2214 feet for this point. The Hoover and Schaller wells give elevations of 2307 and 2290 feet, respectively, for the top of the Red Beds. The exposures of the top of the Red Beds on the Canadian River show elevations of 2273, and, to the east, of approximately 2295 feet. North of the Canadian River the Hopkins and Ruby Jones wells show such low elevations for the top of the Red Beds that it is probable that they were eroded prior to the deposition of the terraces which cover that area. This was brought out in the discussion of the history of the Canadian River. In the Santa Fe well at Canadian the top of the Red Beds may also have been eroded, giving the low elevation that is seen on the map. Between the George and Gibson wells and the outcrop of the Red Beds on the Canadian River there is a general dip to the east with a north component. Disregarding any irregularities which may be present, the northeast dip is approximately 6 feet to the mile, as determined from the above data. This dip on the top of the Red Beds corresponds to that of 8 feet to the mile, as determined from the Lower Pliocene beds.

There is slumping present in the Lower Pliocene beds which is quite obvious in certain parts of the county. In the isolated area of undifferentiated Lower Pliocene in the northeast corner of the county, there is a great deal of slumping, with the result that there are erratic slopes, isolated mesas and escarpments of lower elevations than that of those adjoining, and a few small mesas which are saddle-shaped in profile. Considering the slumping as a whole, it is more prevalent in the eastern corner of the county than in the remaining area. It has been noted that all of the slumping is not toward the creek valleys, nor confined to them, and that a number of outcrops near large valleys show no such movement. In a number of instances it seems as though the slumping was brought about by agencies in the Red Beds, such as cavities formed by solution of salts.

The Anadarko basin has been postulated north of the Amarillo uplift, though its exact position is not well defined. In Oklahoma the basin has been well defined and represents a trough passing north of the Wichita Mountains and extending southeastward nearly to the Arbuckle Mountains. In Hemphill County the authors believe that the axis of the Anadarko basin continues along the approximate

strike as in Oklahoma and parallels the Canadian River. Data on which this opinion was based were obtained from well logs and will be found in the correlation sheet, "Well Data—Correlations." The Lower Pliocene does not show this basin, nor does the top of the Red Beds, as the latter was planed off prior to the deposition of the Lower Pliocene.

Subsurface Correlations.—Correlations which appear on the diagram have been made between the wells by using the most reliable data. The top of the Red Beds is fairly well defined in all of the logs. In the case of the Red Beds with their included salt series, a more or less definite zone is displayed in the logs which affords a general and safe correlation. In order to reduce the margin still more, first the base of the Red Beds was used, then the base of the lower salt series. Another correlation, although not so satisfactory as the above two, was made on top of an indefinite "lime" (probably anhydrite) series. From the correlation sheet it will be seen that the three datum planes correspond with one another in a fair manner, and that they may be relied upon for a rough comparison as to thickening and thinning between wells.

Varying amounts of Red Beds were eroded prior to the deposition of the Lower Pliocene, and probably subsequent to it in some places. The Santa Fe water well at Canadian and the two wells, Hopkins and Ruby Jones, north of the Canadian River, show abnormally low elevations for the top of the Red Beds, and it is suggested that this may be due to erosion before the deposition of the terraces which are believed to cover these areas; that is, pre-Lower Pliocene and further pre-Lower Pleistocene erosions are postulated.

The Hoover well is the only one within the area that has afforded samples of cuttings. The descriptions and determinations of the horizons in this well were made by Mr. Charles Laurence Baker.

Company and Well	Elevation in Feet	Data on Base of Red Beds	Data on top of Main Lime "Series"	Data on Base of Lower Salt Series
Fisher Oil Company, No. 1 George	2860	plus 60	minus 310	plus 497
Hoover et al, No. 1 Hoover	2535	minus 200	minus 740	plus 245
Fort Worth-Canadian Oil Company, No. 1 Schaller	2540	plus 395 ?	minus 226 ?	no salt logged
Piney Oil & Gas Company, No. 1 Hopkins	2370	minus 345	minus 810	plus 230
Ruby Oil Company, No. 1 Jones	2685	minus 45	minus 445	plus 385
Gibson Oil Corporation, No. 1 Jones	2852	plus 97	minus 413	plus 452

WELL DATA

The following is a summary of the available data on the wells in Hemphill County and adjoining counties.

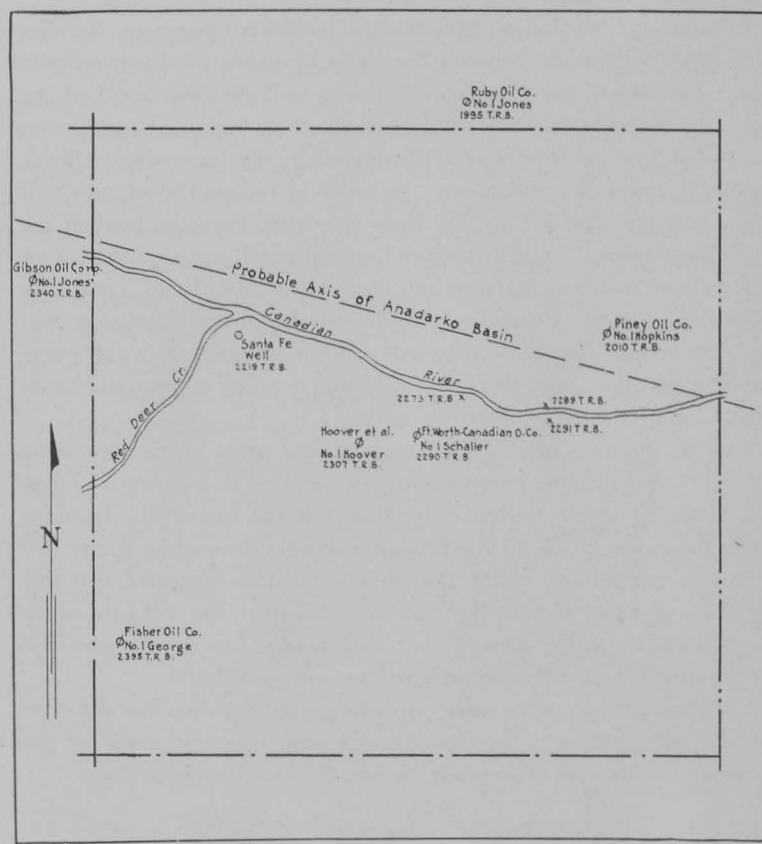

Fig. 9. Sketch showing elevations of the top of the Red Beds, Hemphill County, Texas.

Well and Company	Elevation, Feet	Total Depth, Feet	Lower Pliocene, Feet	Cenozoic, Feet	Double Mountain and Clear Fork, Feet	Wichita, Feet	Cisco, Feet	Top Panhandle Big Lime, Feet	Canyon, Feet
Hoover et al, No. 1 Hoover	2535	5055	0–228		228–2735	2735–3840	3840–	4025	Probably reached[3]
Piney Oil & Gas Co., No. 1 Hopkins	2370	3500		0–360	2715–		Probably not reached		
Fisher Oil Co., No. 1 George	2860.5	3542	0–465		465–2800	2800–	Probably not reached		
Fort Worth-Canadian Oil Co., No. 1 Schaller	2540	3400	0–250[4]						
Gageby well		600±	380						
Drilled for oil in 1928.									
Gibson Oil Corporation, No. 1 Jones	2852	4200	0–512		512–2755	2755–	Probably not reached[5]		
Ruby Oil Co., No. 1 Jones[6]	2685			0–690	690–2730	2730–	3850		

[3]Temporarily abandoned. The above determinations are from samples and log. Several oil shows were reported in this well and a trace of gas from between 4824 and 5055 feet. (See description of samples.)

[4]Log of this well is extremely unreliable.

[5]This well is in Roberts County.

[6]This well, in Lipscomb County, was drilling at the time of the investigation at a depth of 4400 (?) feet. There was an oil show present on the pit and reported as good and reliable. Water trouble was encountered in this well. Samples were later procured to a depth of 4945 feet, at which depth the well was still in the Panhandle Big Lime, the top of which was probably at 3850 feet. No samples between 3900 and 3995 feet.

Determination of samples from Hoover et al, No. 1 Hoover, Hemphill County: Samples from this well between the depths of 3320 and 4942 feet were obtained through the courtesy and coöperation of Mr. H. E. Hoover of Canadian. These, as determined by Mr. Charles Laurence Baker, are as follows:

	Depth in Feet
Anhydrite; gray clay; some limestone	3320–3790
Limestone, buff. Panhandle Big Lime. Same material at 4055, 4065, 4068, 4085–4097 feet	4025
Limestone, buff; very cherty	4150
Fusulina limestone; gray; cherty. Same at 4169 feet	4165
Fusulina limestone, gray; very cherty. Same at 4205	4195
Limestone, buff	4220
Limestone, gray; cherty	4220–4225
Limestone, buff; cherty	4225
Limestone, white to buff. Same at 4245	4240
Limestone, gray; cherty. Same at 4260, 4265	4255
Limestone, gray; very cherty. Same at 4280, 4290	4275
Shale, dark gray; limestone, light gray; some bentonite Same at 4320, 4340, 4365	4300
Limestone, gray; shale, dark gray	4365–4370
Limestone, gray	4400–4405
Limestone, gray; transparent chert	4405–4415
Limestone, gray	4415–4419
Limestone, gray; very cherty	4550–4555
Shale, dark gray; limestone, light gray. Same at 4570–4573	4565–4570
Limestone, gray, light	4660
Limestone, gray; cherty	4660–4665
Shale, very dark blue-gray	4845–4856
Limestone, light buff; shale, black	4860–4885
Shale, very black, very carbonaceous; plant fossils	4885
Limestone, gray; caving, black, carbonaceous shale	4935–4942

ECONOMIC GEOLOGY

Underground Waters.—In The University of Texas Bulletin 57, "Geology and Underground Waters of the Northern Llano Estacado," Baker discusses fully the water conditions of this section, including Hemphill County. This county derives all of its water from the Cenozoic beds at depths of from a few feet to several hundred feet. There appear to be no barren areas and no difficulties in producing the water. The authors have made no analyses of the

water, but as far as could be ascertained it is all of excellent drinking quality. Within the county it is not used for irrigation. Windmills are plentiful, there being one to about every two square miles. Along the major streams, which have cut down to the groundwater level, there are seep springs which form marshy places. By using the accompanying geologic map and the composite section (Figure 2), an estimate of the depth to the Red Beds may be approximated for any part of the county.

Volcanic Ash.—In the western part of the county there is a fair-sized deposit of volcanic ash of apparently local extent. It is situated in the northeast corner of Section 59, Block A-2, and is in the western portion of Coördinate P-3 on the geologic map. There are no other deposits of this character within the county. The ash is exposed in one or two gullies which cut back into a low escarpment formed by the ash and which may be traced for about 400 feet in a northeast-southwest direction and about 50 feet back along the top of the escarpment. The upper part or crust of the ash deposit is heavily impregnated with caliche. The lower portion of the ash is pure and the lime increases upwards in the exposures, or where the overburden forms a protective mantle. The deposit is limited by sand and caliche beds to the north and southeast, but it may have considerable extent to the southwest where it is covered. It is estimated that there are about 46,500 cubic yards of ash available from the exposed portion.

At the base of the exposure there is a bed of gray-green clay overlain by pure ash of coarse texture with a thickness of ½ foot. Above this there are 7 feet of fine-grained ash which is thinly laminated and ripple marked. The overlying 3 feet, that which forms the cap, is probably the same as that immediately below, but it is highly impregnated with caliche.

Gravel.—It is believed that there are deposits of gravel along the Canadian River which are of commercial quality. The material will be found in the numerous exposures of the terraces. In particular, an extensive deposit can be seen along the road which runs north from the river bridges, 5 to 7 miles north of the city of Canadian. Another deposit was observed on the north side of the

Canadian River about 1 mile west of the bridges and south of the highway. Still another extensive deposit was found on the south side of the Canadian River about 7 miles west of the city of Canadian and about 1 mile south of the river road. Other deposits have been seen in the vicinity of the Conatser Ranch and about 1 mile northeast of the Harlan Ranch on the north side of the Canadian. A commercial gravel pit has been operated at the city of Canadian.

INDEX

LEGEND

PLEISTOCENE	Qal	River and Creek Alluvium	
PLEISTOCENE	Qsd	Sand Hills and Dunes	
LOWER ? PLEISTOCENE	Pt_1	No. 1 Terrace	
LOWER ? PLEISTOCENE	Pt_2	No. 2 Terrace	
LOWER ? PLEISTOCENE	? Pt_3	No. 3 Terrace	
LOWER PLIOCENE	Plu	Above No. 1-A Bed	
LOWER PLIOCENE	Plm	Between No. 1 and No. 1-A Beds	
LOWER PLIOCENE	Pll	Between No. 3 and No. 1 Beds	
LOWER PLIOCENE	Plb	Base to No. 3 Bed	
	Plud	Undifferentiated Lower Pliocene	
PERMIAN ?	Pm	Red Beds	

SCALE: 0 1/2 1 2 3 4 5 MILES

N

- Outcrop of No. 1-A Bed and Top of Plains
- Outcrop of No. 1 Bed
- Outcrop of No. 2 Bed
- Outcrop of No. 3 Bed
- Top Cap of Undifferentiated L. Pliocene
- Tops of Terraces
- △A, etc. Primary Triangulation Stations
- x Locs. 1 to 28 Vertebrate Fossil Locations

GEOLOGIC MAP OF HEMPHILL COUNTY, TEXAS

By LYMAN C. REED AND OSCAR M. LONGNECKER, Jr.